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SECOND ALL-UNION SEMINAR ON HYDROMECHANICS AND HEAT AND MASS EXCHANGE IN WEIGHTLESSNESS; SUMMARIES OF REPORTS

G.Z. Gershuni and Ye. M. Zhukovitskiy, Editors

Translation of: "II Vsesoyuznyy seminar po gidromekhanike i teplomassoobmenu v nevesomosti, Tezisy dokladov," Perm', USSR Academy of Sciences, Department of Mechanics and Control Processes, Ural Scientific Center; Institute of Continuum Mechanics of the USSR Academy of Sciences, Ural Scientific Center; Institute of Problems of Mechanics of the USSR Academy of Sciences; Perm' State University; Perm' State Pedagogical Institute; 1981, pp. 1-186.

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16. Abstract

Abstracts of reports are given which were presented at the Second All-Union Seminar on Hydromechanics and Heat-Mass Transfer under weightlessness. Preliminary results of experiments on solid solution crystallization in weightlessness and features of crystallization during capillary shape formation in weightlessness are some of the subjects discussed. Heat and mass exchange in multiphase media and related questions are examined.

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SECOND ALL-UNION SEMINAR ON HYDROMECHANICS AND HEAT AND MASS EXCHANGE IN WEIGHTLESSNESS

SUMMARIES OF REPORTS

1. Some General Laws Governing the Processes of Hydrodynamics, Heat and Mass Exchange with a Change in the Mass Force Field /3 *

V. S. Avduyevskiy and V. I. Polezhayev (Moscow)

The efficient use of weightlessness conditions to produce new substances and materials, and improve their properties, as shown by work of recent years, requires a broad program of basic research on the processes of hydrodynamics, heat and mass exchange. In this case it is important to search for and to investigate the gravitationally sensitive mechanisms based on fairly complete models of hydrodynamic and physical-chemical processes with regard for the specific nature of changes in the weak mass force field in real weightlessness conditions. This report surveys some results of work done in this area.

Certain features of the change in the weak force field in weightlessness are examined. A classification is made of the hydrodynamic and convective processes in nonisothermic liquids and gases that are heterogeneous in composition Especial attention is focused on the effects of interaction between convective elements of varying nature (thermal, concentration convection, effects of double diffusion, rotation).

Phenomena associated with the formation of layered structures and nonmonotonic change in certain characteristics of heat and mass exchange (distribution of temperature, admixture concentration, phase transition rate) with a change in intensity of the hydrodynamic and convective processes are investigated. Capillary

*Numbers in right margin indicate pagination in original text.

effects (questions of free liquid zone stability; effects of heterogeneity due to thermocapillary movements) are examined.

Restrictions on the implementation of technological processes in weightlessness because of the examined effects and trends for future research are discussed.

2. Preliminary Results of Experiments on Solid Solution Crystallization in Weightlessness

B. I. Golovin, V. S. Zinov'yev, A. V. Iz"yurov, N. V. Komarov, L. N. Kurbatov, Ye. N. Kholina, I. V. Barmin (Moscow)

The text of the summaries is presented on p. 166.

3. Features of Crystallization during Capillary Shape Formation in Weightlessness

V. A. Tatarchenko (Chernogolovka)

Methods in which the side surface of the crystal is formed without contact with the container walls have become more widespread in recent years. These are the methods of Chokhral'skiy, Stepanov, Kiropulos, Verneyl' and the floating zone. A similar situation develops in weightlessness during crystallization in an ampoule if the melt does not contact the ampoule walls, and during directed crystallization of freely suspended spherical melt drops. The shape and size of the obtained crystal in all of these cases are determined by capillary forces that form a meniscus in the interphase boundary zone, and by heat and mass exchange conditions in the crystal - melt system.

This report analyzes these phenomena in order to clarify the effect of the crystallization plan and conditions on the shape, dimension of the crystal grown and the stability of the crystallization process. The analysis implies joint solution to the melt motion equation (Navier - Stokes equation) with boundary condition on the free meniscus surface (Laplace capillary equation), continuum equation (law of mass preservation),

equation of heat conductivity (law of energy preservation), diffusion equation (admixture mass preservation) and use of constant growth angle which is specific for the crystallization. This system of equations is common for all the examined crystallization methods, while the individual features of each method are /5 characterized by a system of boundary conditions and specific values of the parameters included in the equation. The approach suggested here is correct if the limiting stage is not the crystallization kinetics, but the heat and mass transfer conditions which are usually fulfilled for real systems and extension systems. However the kinetic effects, for example, the dependence of supercooling on the front on the crystallization rate, or the effect of an admixture on the crystallization temperature, can be taken into consideration in the framework of the model developed here. Questions of crystal quality are not left out here. Unstable growth is generally accompanied by severe oscillations in the crystallization rates, which results in an increase in the number of defects. It has been experimentally established that there is an increased number of bubbles and nonuniform distribution of admixture at the sites of crystal constriction accompanying unstable growth.

Each of the crystallization methods examined here can be characterized by a finite number of main variables. Thus, in the Chokhral'skiy, Stepanov and Kiropulos methods this will be the size of the crystal and the position of the crystallization front in relation to the free melt surface or the shape-former edge; the volume of the melted zone and the position of the melting front, etc. are added to it in the melted zone method. These quantities (x_i) are generally functions of controllable parameters of the crystallization process and satisfy the following system of differential equations obtained on the basis of the basic ratios listed above:

$$\frac{\partial x_i}{\partial t} = f_i(x_1, x_2, \ldots, x_n, c), \qquad i = 1, 2, \ldots, n. \tag{1}$$

Here t is the time, n is the number of unknowns which depends on the crystallization method and the cross section of the obtained crystal, C is the set of controllable parameters of crystallization, thermophysical and other constants of the crystallized substance.

Crystallization in weightlessness introduces a number of peculiarities into statement of the problem. The capillary problem changes severely. It is necessary to take into consideration the Marangoni convection, which in turn influences the /6 results of solving the capillary and thermal problems. All of this can radically alter the result. The lack of the gravitational force for the Verneyl' method thus stabilizes production of large diameter crystals, while the process of producing these crystals is unstable when there are gravitational forces.

SECTION 1.
TECHNOLOGICAL EXPERIMENTS IN WEIGHTLESSNESS AND THEIR INTERPRETATION /7

1.1. Growing Three-Dimensional Germanium Monocrystals by the Directed Crystallization Method in Microgravity

V. T. Khryapov, V. A. Tatarinov, T. V. Kul'chitskaya, N. A. Kul'chitskiy, Ye. V. Markov, R. S. Krupyshev (Moscow)

A series of technological experiments to grow germanium monocrystals alloyed with gallium by the method of directed crystallization [1] was continued on the Kristall apparatus on board the Salyut - 6 station in order to study the effect of weightlessness on structural and electrophysical properties of crystals and segregation processes.

The experiments used cylindrical samples 8 mm in diameter and 60 mm long, cut from crystals obtained by the method of Chokhral'skiy. After the melt was homogenized for 120 min., the ampoule was moved at a rate of 0.188 mm/min in relation to the furnace thermal field.

The results of studying the crystals obtained in the last series of experiments confirmed the main conclusions regarding the positive effect of weightlessness on growth of crystals from a melt. However, this series noted a certain deterioration in the crystal quality as compared to the samples previously obtained. Whereas the crystal obtained in the first series of experiments grew with a free growth surface, the surface of free growth of the crystals in the last series was about one-fourth of the entire surface.

The phenomenon of growth with free surface that was noted in the first series of experiments resulted in a deterioration in the degree of structural perfection of the monocrystals. A decrease occurred in the space samples in the dislocation density to 2×10^3 cm^{-2} as compared to the seed crystal, while in the terrestrial analogs it increased to 10^5 - 10^6 cm^{-2} because of deformation in the growing crystal by the restricting container walls. There is an increased dislocation density to 1×10^5 cm^{-2} in the crystal grown in space in this series of experiments, as under terrestrial conditions. /8

A decrease has been noted in the level of microsegregation of the admixture in the crystals obtained in space. The level of axial and radial microheterogeneity of admixture distribution evaluated as the ratio $\Delta\rho/\rho_{med.}$ was 2 - 3 - fold lower in space samples than in terrestrial.

The observed deterioration in the quality of the crystals obtained in the last experimental series as compared to the first is due to the increased level of residual accelerations associated with conducting the growth processes during the day with active movements of the cosmonauts; the magnitude of g-forces in this case according to the readings of the acceleration indicators rose from 10^{-7} - 10^{-6} g/g in the first case to 10^{-4} - 10^{-3} g/g_0 in the last.

It was demonstrated as a result of the conducted studies that high-quality monocrystals can be grown from the liquid phase only with strict monitoring and minimum level of residual accelerations.

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1.2. Study of $Pb_{1-x}In_xTe$ Crystals Obtained by the Bridgeman Method on the Kristall Unit in the Salyut - 6 Orbital Station /9

O. V. Abramov, S. A. Sver'kov, I. P. Kazakov, O. I. Rakhmatov, Zh. Yu. Chashechkina (Moscow, Chernogolovka)

The experiments on growing semiconductor crystals in space that were conducted in previous years indicate a number of interesting phenomena that accompany crystallization from the liquid phase. They should include anomalous macro- and microsegregation effects, improvement in the crystal structure and the phenomenon of restricted melt contact with the container walls. These experimental facts need to be generalized for the most diverse materials whose production is of practical importance. These materials include lead telluride and solid solutions based on it.

This work presents the results of studying $Pb_{1-x}In_xTe$ crystals of composition $x = 0.0041$ obtained from a melt in microgravitational and terrestrial conditions.

The crystals were grown by the Bridgeman method on the Kristall apparatus placed on the Salyut-6 orbital scientific station. A control experiment was conducted under terrestrial conditions using a vertical variant of the method on similar apparatus. The crystals were grown in a quartz ampoule that was

evacuated to 10^{-5} mm Hg with seed crystal cone; the ampoule inner diameter was about 8 mm, the total length of the obtained bar was about 30 mm.

The surface of the obtained bars was studied using a scanning electron microscope. Indium distribution was studied by the method of electron probe microanalysis. The phase composition was studied by methods of x-ray structural analysis.

The temperature relationships of the Hall coefficient and specific resistance were studied by the Van der Paw method in the 80 - 293°K range.

Studies of the surfaces of the obtained bars indicated that the surface of the terrestrial bar whose formation was governed by contact between the growing crystal and the ampoule wall, was predominantly smooth, with small number of pores about 50 μm in /10
size. The surface structure of the space bar is similar to the surface pore structure of the terrestrial bar. Since one can assume that formation of the surface inside of the pore occurred without contact between the melt and the ampoule wall, then during growth of the space sample, contact between the melt and the inner surface of the ampoule was very insignificant.

X-ray structural analysis showed that the $Pb_{1-x}In_xTe$ crystals that were obtained both under terrestrial and space conditions are monocrystals with block size to about 50 μm.

Study of admixture distribution indicated that the admixture distribution (In) in the space bar is more uniform as compared to the bar obtained under terrestrial conditions. Inclusions were found in the terrestrial bar which were enriched with indium; there were no inclusions in the space bar. Based on measurements of the Hall coefficient and the specific resistance, it was indicated that both the space and terrestrial samples have n-type of conductance and have carrier concentration of $n = 6.5 \times 10^{18}$ cm^{-3} and mobility $\mu = 14{,}000$ $cm^2/B \times C$ at 80°K.

1.3. Crystallization Features of Some Semiconductor Materials in Microacceleration Conditions /10

N. A. Verezub, E. S. Kopeliovich, L. V. Nazarova, V. V. Rakov (Moscow)

Reasons were examined for the development of heterogeneity in the semiconductor crystals under terrestrial and microacceleration conditions. An experimental program was presented to investigate the mutual diffusion of components in the gallium - arsenic system and study the possibility of producing monocrystal layers by the method of liquid-phase epitaxy. Results are presented of preliminary criterial analysis of the "Diffusion" experiment which indicated the dominance of concentration convection over thermal. A comparative study was made of the sample after experiments under laboratory and microacceleration conditions. Epitaxial gallium arsenide layers were obtained with distinct dependence of the thickness change on the growth conditions. /11 The structure of the epitaxial layers of GaAs and the distribution of GaAs inclusions in the gallium volume between the GaAs plates were studied.

1.4. Measurement of Inertia Forces and Accelerations on Board an Orbital Station

S. D. Grishin, S. S. Obydennikov, V. V. Savichev (Moscow)

As the program of scientific research work done on the orbital stations expands, the interest in determining the level of weightlessness on these apparatus increases. Calculations show, for example, that when experiments are conducted on space materials technology, increase in acceleration level on board the station by one - two orders could result in a change in the mechanism of heat- and mass-transfer in the melts, and consequently, change in the occurrence of technological processes and properties of the obtained materials [1]. An analysis was made of the different perturbations developing during the flight.

The absolute values of accelerations caused by these perturbations are evaluated. Results are presented of measurements on board the orbital scientific complex Salyut - 6 - Soyuz - Progress of low accelerations using the IMU developed accelerometer. It is shown that the absolute values of accelerations for each of the base axes and their ratios depend on the operating conditions of the complex, its on-board apparatus and the activity of the operators. Vibrations are observed in the station housing with oscillation frequency in the cross section of the station about 1.75 Hz and in the longitudinal direction about 0.9 Hz, as well as oscillations with lower frequency about 0.4 Hz. In the majority of studied conditions, accelerations in the cross section are roughly an order higher than the magnitude of acceleration along the longitudinal axis of about 1×10^{-4} g_0.

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1.5. Admixture Distribution in Crystals Grown in Weightlessness /12

N. Yu. Anisimov, L. V. Leskov (Moscow)

Distribution of admixtures in semiconductor crystals is one of the most important characteristics of the crystal which determine its practical value. One of the main goals of space technology is to obtain semiconductor crystals with high degree of homogeneity in admixture distribution.

In the majority of cases, in crystals that were obtained in weightlessness by the method of directed crystallization, a considerable segregation is observed in the admixtures over the length of the samples, which indicates the presence of convective mixing in the melt [1, 2]. Mixing of the melt in weightlessness is guaranteed by Marangoni convection which develops on an essentially free surface of the melt. By using boundary conditions on the free surface, condition of continuity, and also

assuming that the flow near the free surface has the nature of a boundary layer, one can obtain for the flow velocity on the surface u_s and average flow velocity in the volume u_V

$$u_s \simeq \nu(\Delta\sigma L/\rho\nu^2)^{2/3}/L,$$
$$u_V \simeq 2\nu(\Delta\sigma\cdot L/\rho\nu^2)^{1/3}/R,$$

where $\Delta\sigma$--drop in surface tension, L--length of ampoule, R--its radius, ρ--density, ν--melt viscosity.

For the thickness of the diffusion layer on the crystallization front, we obtain $\delta_D \cong 3.5R\ (\Delta\sigma/\rho D)^{-1/6}$, where D--coefficient of admixture diffusion. Knowing the thickness of the diffusion layer and the growth rate permits computation of the amount of effective distribution coefficient, and correspondingly, the distribution of admixture over the length of the sample from formulas $C_s(x) = kC_o(1 - x/L)^{k-1}$, where K--effective distribution coefficient, C_o--initial admixture concentration. The calculation results satisfactorily agree with the experiment [2].

If the admixture changes the suface tension of the melt, then /13 admixture redistribution occurs in the melt. In this case, by knowing the initial distribution of admixture $C_o(x)$, one can obtain

$$C_s(x) = K\cdot C_o(0)(1-x/L)^{K-1}\left[1+\int_0^{x/L}\frac{dC_o(s)}{C_o(0)\,ds}(1-s/L)^{1-K}\,ds\right].$$

If the residual acceleration is not aimed along the ampoule axes, then through joint action of Marangoni convection and natural concentration convection, heterogeneity develops in the admixture distribution in the sample cross section

$$(\Delta c)^{1/3} \sim \left[\left(\frac{\partial\sigma}{\partial c}\right)^2\rho\nu^2\right]^{1/3}\Big/\left[g\,\frac{\partial\rho}{\partial c}\,R^{7/3}\right].$$

where g--level of residual accelerations in a direction perpendicular to the ampoule axis.

The calculation results are in qualitative agreement with the results of the experiment to obtain a solid solution of Ge - Si in the Soyuz - Apollo program [3].

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Dynamic Melt Stability in a Cylindrical Ampoule in Weightlessness

N. Yu. Anisimov and L. V. Leskov (Moscow)

The majority of technological experiments that have been conducted by now have been carried out in ampoule furnaces. The majority of promising technological units belong to this same type. A significant feature of the space technology processes /14 is that in many cases the melt is separated from the ampoule wall (including if the melt does not wet its walls) [1, 2].

In order to analyze this phenomenon, an examination was made of the behavior of the melt in a cylindrical ampoule with directed crystallization. The attempt of the liquid in weightlessness to adopt the shape of a sphere is prevented by the presence of the ampoule walls. The capillary pressure $p_o = 2\sigma|\cos\theta|/R$ (σ--surface tension, R--ampoule radius, θ--contact angle) which develops in the liquid because of twisting of the face surface of the melt "presses" the melt to the ampoule walls. If there are heterogeneities in the inner diameter of the ampoule on the order of h, then with a distance between them of no more than $a_* \cong$

$2\sqrt{hR\sec\theta}$, "hovering" of the melt between these heterogeneities occurs. Equilibrium of the liquid surface in this case is stable in relation to the small perturbations, which could be vibrations. The condition of small perturbations is written as $h > a_o/w_s^2$, where a_o--amplitude of acceleration oscillations. It is a consequence of the described mechanism that with an increase in ampoule diameter, there is a decrease in the area of the contact sections.

The characteristic quantity for capillary pressure for standard semiconductor materials is on the order of 1 gPa. When the substance contains Hg, S, P and Zn admixtures which have high ($> 10^3$ gPa) pressure of saturated vapors under experimental conditions, then another mechanism is likely for separating the melt from the ampoule walls which is associated with the formation of a "steam cushion."

The stability of the melt surface can also be improved using a variable magnetic field. If the sample is placed in a solenoid through which trapezoidal current pulses are passed, then the ratio of the magnitudes of capillary and magnetic forces can be characterized by the criterion

$$K = B^2R^2/\sigma\sqrt{\mu_0\rho\tau} = (n^2 I^2 R^2/\sigma)\sqrt{\mu_0^3/\rho\tau},$$

where B--average magnitude of the magnetic field, ρ--specific resistance, τ--pulse increase time, n--number of solenoid loops per unit of length, I--average magnitude of current in a pulse. If the following condition is fulfilled

$$\mathcal{N} = K\frac{\sigma L}{\lambda\,|\nabla T|\,\tau R} \ll 1,$$

where λ--heat conductivity, $|\nabla T|$--temperature gradient in the melt, L--length of sample, then the heat release in the melt which is associated with the eddy currents will not "ruin" the /15

thermal conditions of the unit. According to estimates under typical conditions of technological experiments, the magnitude of magnetic field B about 10^{-2} Tl with duration of τ about 10^{-3} sec is sufficient.

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SI.1. Mechanism and Kinetics for Crystallization Processes with Reduced Gravitation

T. A. Cherepanova, V. V. Ilyukhin (Riga, Moscow)

Occurrence of heat and mass transfer during crystallization is examined with regard for atomic kinetics on the surface of the growing edges with different degree of gravitation. In examples of specific systems, the effect of natural and thermocapillary convection on the configuration of the interphase boundaries, distribution of the concentration and temperature fields in the phases with zonal melting and directed crystallization of multi-component crystals are discussed. Critical velocities at which the diffusion mass transfer processes from the melting front to the growth front lose stability are evaluated. Dependences are presented for the length of the liquid zone during zonal melting on the crystallization rate.

SI.2. Growing PbTe Monocrystals by Zonal Melting Method with Solvent /16

I. P. Kazakov (Moscow)

PbTe monocrystals from a solution in lead were grown by the method of moving heater. Using hardening, forms are defined for the interface surface on the boundaries of growth and

dissolving. The findings confirm the results of computations made in publication [1].

Measurements of the specific resistance and the Hall coefficient were used to compute the concentration of charge carriers $n = 5.5 \times 10^{17}$ cm^{-3} and mobility $\mu_n = 5 \times 10^4$ cm^2/V x sec with temperature 77°K.

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SI.3. Thermocapillary Convection near the Crystallization Front during Growth of InSb Crystals in Weightlessness

I. V. Barmin, V. S. Zemskov, A. S. Senchenkov, M. R. Raukhman, S. M. Pchelintsev (Moscow)

Publication [1] to clarify the admixture distribution features in an indium antimonide crystal grown in an ampoule on the Splav unit on the Salyut-6 orbital station advanced a hypothesis about the presence of a mobile zone of thermocapillary convection in the melt near the crystallization front. This publication presents results of computing the free surface of the melt and the velocity field in the melt for conditions of conducting this experiment.

The angle of wetting the graphitized ampoule walls by the melt that is needed to compute the shape of the free melt surface was determined based on the shape of the InSb crystal that was grown in a similar ampoule on the Earth in a vertical position. /17
A plan is presented for computing the magnitude of this angle. It was indicated that the presence of even a short free melt surface with temperature gradient along it on the order of 10 deg/cm causes fairly intensive convective flow in the liquid which essentially develops before the ampoule axis and encompasses the region along the ampoule that considerably exceeds the zone with the free melt surface. A comparison is also made of the

flow pattern in the flight crystal and in its ground analog. A distribution is made of the admixture over the length of the terrestrial crystal grown in a vertical position, confirmining the presence of thermogravitational convection in this case in the entire melt volume.

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SI.4. Numerical Study of Admixture Distribution with Directed Crystallization of a Melt in Cylindrical Ampoules with Different Magnitude of Wettable Surface

G. A. Dolgikh and A. I. Feonychev (Moscow)

When a melt crystallizes in partial weightlessness, the effect of capillary convection on the structure of liquid flow and distribution of melt components increases. The liquid that does not wet the ampoule wall can be completely or partially separated from them in weightlessness [1]. Decrease in the contact surface of the melt with the ampoule walls results in a decrease in dislocations in the growing crystal, but at the same time, there is an increase in the free liquid surface and rise in intensity of capillary convection in the liquid.

The features of thermal and concentration convection under the influence of weak accelerations of mass forces, as indicated in publications [2, 3] can result not in a decrease, but an increase in the radial heterogeneity of admixture distribution in the growing crystal. Publication [3] also shows that the absence of contact between the liquid and the side surface of the cylindrical ampoule governs the characteristic distribution of the gallium admixture in germanium which has the maximum near the axis. This qualitatively corresponds to the data obtained /18

in the MA-060 experiment on the orbital complex Soyuz - Apollo [1].

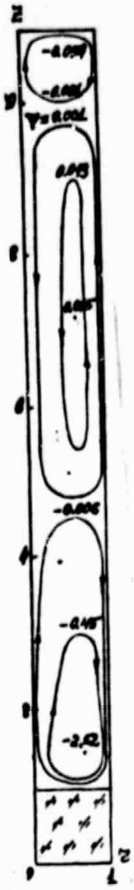
This publication continues the studies started in publication [3]. A study was made of the effect of partial contact of liquid and the side surface of the ampoule on the intensity of convective fluid flow and admixture distribution with regard for movement of the crystallization front on the z axis of the ampoule. The technique of numerical solution to the convection equation in the Boussinesq approximation [3] is used.

Figure 1 shows the lines of fluid current Ψ at moment in time $\tau = 4.523$ on the condition that the liquid does not wet the ampoule wall at a height from the crystallization boundary equal to the radius. The calculation was made for the conditions that correspond to the MA - 060 experiment: the Grashof number for thermal convection equals 10^4, the Grashof number for concentration convection is 10^2, the Marangoni number for thermocapillary convection is 3.25×10^2, the Marangoni number for concentration-capillary convection is 5, the Prandtl number is 0.023, the Schmidt number is 7, the ratio of the ampoule height to the radius $H/R = 11.1$, the rate of movement of the crystallization front is approximated by the relationship $v_{fr} = 0.03 + 0.099\sqrt{\tau - 0.013} + 5.5\ 10^{-4}\ \tau^2$, where $\tau = \nu t/R^2$, ν--kinematic viscosity of liquid germanium, t--current time.

The lower vortex which adjoins the crystallization boundary is governed by the effect of the thermocapillary force on the free lateral surface of the fluid. The middle vortex is caused by the effect of thermal convection in the fluid, and the upper is due to thermocapillary convection through the gradient of the surface tension force on the face surface $z/R = 11.1$. With complete wetting of the side wall, the upper vortex disappears, and with complete removal of the fluid from the side wall, the middle vortex drops, and the lower and upper are united.

Figure 2 shows the distribution over the radius of the ampoule of dimensionless concentration of gallium admixture in

Figure 1.



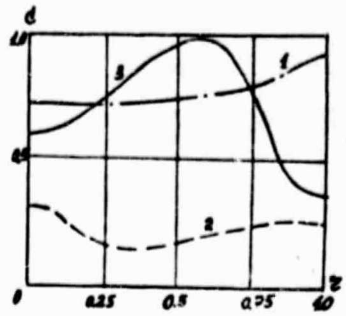


Figure 2.

germanium from the section $z_1/R = 0.5$, where z_1--distance from the crystallization boundary with $\tau = 4.523$. Curve 1 corresponds to the condition of complete wetting by fluid of the ampoule wall, curve 2 corresponds to complete nonwetting, curve 3 corresponds to nonwetting to a height from the surface of crystallization equal to the radius. The dimensionless concentration of admixture $C = \dfrac{C - C_o}{C_s - C_o}$, where C_o--initial concentration, C_s--concentration on the crystallization boundary (constant in time).

The findings indicate the strong effect of wetting conditions by fluid of the ampoule walls on the structure of convective flow and on the radial distribution of the admixture near the crystallization boundary.

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SI.5. Reasons for Admixture Macrosegregation in Technological Experiments on Direct Crystallization in Weightlessness

S. A. Nikitin and A. I. Fedyushkin (Moscow)

SI.6. Study of Chemical Gas Transport of Germanium in the Ge - GeI_4 System during Microgravitation /20

V. T. Khryapov. S. I. Rozhkov, N. A. Kul'chitskiy, V. M. Biryukov, Ye. V. Markov (Moscow)

A series of experiments to study the effect of the gravitational force on mass transfer of germanium in the Ge - GeI_4 system was made on the Kristall apparatus installed on board the Salyut - 6 station in microgravitation ($g \leq 10^{-4}$ m x sec^{-1}) and on a similar apparatus on Earth.

Experiments were conducted in quartz ampoules with inner diameter of 0.35 cm, in gradient zone of the furnace (dT/dx = 80 deg x cm^{-1}). The distance from the source to the settling zone was 4.5 and 1.5 cm (ratio of length to diameter of the ampoules l/d = 13 and 4.5). Settling out of germanium occurred in the cold end of the ampoules in the form of individual crystals 0.1 - 0.5 mm in size. In order to separate the transferred germanium from the germanium iodides before the ampoules were opened, they were distilled from the settling zone. The rate of germanium mass transfer was determined from the change in the weight of the source and by the quantity of substance transferred to the cold end of the ampoule.

Synchronous experiments were conducted on Earth with different arrangement of the ampoule (and temperature gradient) in relation to the direction of the gravitational force. In this case, the direction of transfer coincided (position I), was perpendicular (position II) and opposite (position III) to the direction of the gravitational force.

For the system with l/d = 13, the experiments were conducted in the pressure range of the transport agent from 1 to 20 atm, and for the system with l/d = 4.5, from 1 to 7 atm. Graphs of experimental dependences of the rate of mass transfer of germanium on pressure of the transport agent in the system for conditions

of microgravitation and terrestrial conditions are presented in figures 1 and 2.

Analysis of the obtained results using different models of transfer (1 - 3) indicated that in microgravitation without natural convection, mass transfer in the gas phase occurs mainly by the diffusion mechanism, although there is apparently a certain /21 contribution from other transfer mechanisms (which is indicated by the noticeable increase in transfer rate with increase in pressure of the transport agent).

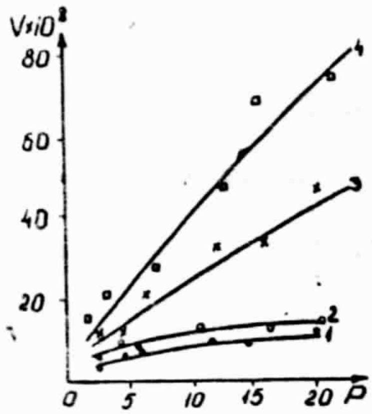

Figure 1. Dependence of Mass Transfer Rate V (mole $cm^{-2}sec^{-1}$) on Pressure p (atm) of Transport Agent in Ampoule, 1/d= 13

Key:
1. Space experiment
2. Earth experiment (position I)
3. Earth experiment (position II)
4. Earth experiment (position III)

Mass transfer under terrestrial conditions with high pressures occurs mainly through thermal convection, and resistance of the system to development of convection [4] and the contribution of the convective component to transfer significantly depend on the arrangement of the ampoule in relation to the direction of the gravitational force.

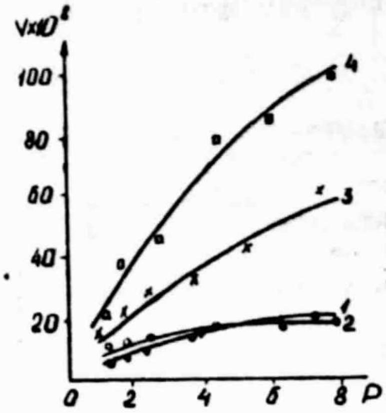

Figure 2. Dependence of Mass Transfer Velocity V (mole $cm^{-2}sec^{-1}$) on Pressure p (atm) of Transport Agent in Ampoule , l/d = 4.5

Key:
1. Space experiment
2. Earth experiment (position I)
3. Earth experiment (position II)
4. Earth experiment (position III)

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S.I.7. Growth Rate of Crystals from Vapor Phase under Conditions Close to Weightlessness

S. I. Alad'yev (Moscow)

This work covers determination of the average growth rate of crystals from vapor-gas media in cylindrical horizontal ampoules with radius r_o with small Rayleigh numbers Ra < < 1. The bases of the ampoules are surfaces of the source and backing.

It is assumed that the medium is a binary mixture of two gases, active with mass concentration C, and inert. A case is examined where the growth process occurs by diffusion kinetics, i.e., the growth rate is determined by the transport substance.

In the cylindrical coordinate system r, θ, x, with beginning in the backing center, the concentration equation for the vapor - gas medium and the boundary conditions are written in the form

$$\begin{gathered}\frac{Pe}{2}\left(v_R \frac{\partial\varphi}{\partial R} + v_\theta \frac{1}{R}\frac{\partial\varphi}{\partial\theta} + v_x \frac{\partial\varphi}{\partial x}\right) = \Delta\varphi; \\ \varphi(x^+, R, \theta) = (\partial\varphi/\partial R)_{R=1} = 0, \quad \varphi(0, R, \theta) = 1, \\ \Delta = \frac{\partial^2}{\partial R^2} + \frac{1}{R}\frac{\partial}{\partial R} + \frac{1}{R^2}\frac{\partial^2}{\partial\theta^2} + \frac{\partial^2}{\partial x^2}, \quad \varphi = \frac{c - c^+}{c^- - c^+}, \\ x = X/r_0, \; R = r/r_0, \; Pe = 2 r_0 v_0/D, \quad v_i = V_i/v_0.\end{gathered} \tag{1}$$

The indices "+" and "-" refer to the values of the source and the backing respectively. The diffusion number Pe is constructed from the average rate of Stefan flow v_0 which can be determined by the expression

$$v_0 = \frac{DH}{\pi r_0}\int_0^{2\pi}\int_0^1 \left.\frac{\partial\varphi}{\partial x}\right|_{x=0} R\,dR\,d\theta, \quad H = \frac{c^+ - c^-}{1 - c^-} \tag{2}$$

With small Rayleigh numbers Ra < < 1, distribution of the velocities is assigned by the expressions /23

$$\begin{gathered}v_R = 2Ra\, f_1(R)\cos\theta, \\ v_\theta = -2Ra\, f_2(R)\sin\theta, \\ v_x = 2(1 - R^2) - 2Ra\,\frac{Pe}{Pr}\, f_3(R)\cos\theta, \\ Ra = g\beta A r_0^4/(\nu a), \; A = 2q_c/(r_0 \rho c_p v_0), \quad Pr = \nu/a.\end{gathered} \tag{3}$$

Here a, ν--coefficients of temperature conductivity and kinematic viscosity, q_c--density of heat flux on the wall.

The rate of the Stefan flow which coincides in magnitude with the volumetric flow of the active component on the backing surface was previously unknown and could only be defined from joint solution to equations (1) and (2).

With a growth of the monocrystals, the Reynolds numbers are also small. In solving tasks (1) - (2) in relation to this, by expansion for small Ra and Pe parameters

$$\varphi = \varphi_0 + \mathcal{R}a\,\varphi_1 + \dots, \qquad \varphi_i = t_0 + Pe\,t_1 + \dots, \quad i = 1, 2, \dots$$

we find

$$v_0(\mathcal{R}a \ll 1) = v_0(\mathcal{R}a = 0) = -\frac{D}{\ell_0 x^+} \cdot \frac{2H}{2-H} \cdot \tag{4}$$

Consequently, with small Pe and Ra numbers, natural convection does not have an influence on the average growth rate of the crystals, which significantly distinguishes the examined case from the growth in vertical ampoules.

The table presents a comparison of the results of the computation and the experiment set up in weightlessness. The crystal growth occurs using chemical transport

$$GeSe_{(s)} + GeI_{4\,(g)} = 2GeI_{2\,(g)} + \tfrac{1}{2}Se_{2\,(g)}$$

An active component in this case is the mixture of gases GeI_2 - Se_2. The flow of GeSe on the backing surface is determined by the formula /24

$$I = \alpha \rho v_0.$$

where α--ratio of molecular weight GeSe to molecular weight of the active component, ρ--density of steam and gas mixture.

1×10^7 Theory	1×10^7 Experiment	n
0.95	1.22	0.00478
1.90	2.74	0.0103
11.5	7.6	0.0295
12.5	15.2	0.151

The discrepancy between theory and experiment, in addition to everything else, could be linked both to the lack in the experiment of direct measurement of the source and backing temperatures, and the approximate computation of diffusion coefficients for which intentionally underestimated values were adopted.

SI.8. Setting up an Experiment on Mechanism and Kinetics for Titanium Production by Metal-Thermal Method

I. M. Kirko and E. A. Iodko (Perm', Berezniki)

The method for producing titanium in industry that currently exists in our country and abroad is essentially reduced to the following resulting reaction:

$$TiCl_4 + Mg \rightarrow Ti + MgCl_2 .$$

This process actually occurs in a much more complicated manner, in several stages, with the formation of intermediate products of the lowest titanium chlorides: $TiCl_2$, and possibly, $TiCl_3$.

Our laboratory made a significant step in creating a mathematical model of kinematics and heat and mass exchange of /25
this process. Based on this model, technological recommendations were developed for the Berezniki Titanium and Magnesium Combine. They were verified in industrial cycles for producting titanium and improved the quality of the titanium foam. The further development of this method is halted by the significant obscurity of the role of different paths for the aforementioned reaction.

It is suggested that an experiment be set up in weightlessness with magnesium and sodium spheres heated by induction

currents until melting, with their fixing in space by electromagnetic forces. These liquid metal spheres will interact with the titanium tetrachloride vapors, while the liquid and solid reaction products will diffuse into the liquid metal sphere. The gaseous reaction products will be condensed on special radial planes.

Metallographic and chemical analysis of the solid sphere conducted after the experiment in the terrestrial laboratory will make it possible to determine the mechanism and kinetics of the reaction and to elucidate many disputed questions.

The technique of our experiment can be preliminarily adjusted under terrestrial conditions.

SI.9. Calculation of Microaccelerations on Board an AES in a Gravitational Stabilization Mode

A. P. Lebedev and V. I. Polezhayev (Moscow)

A technique is presented for computing the forward and rotational perturbing accelerations on board an AES based on numerical integration of canonical motion equations in relation to the center of masses with regard for atmospheric perturbations. The Tisseran equation for a circular orbit having an analytical solution was used as a test for the computation program.

For spacecraft model type Salyut - Soyuz with orbital flight in a gravitationally stabilized position, the change in time of the mass force field was computed. It was shown that the gravitational oscillations of the AES and the effect of the /26 aerodynamic forces result in the appearance of sign-variable rotational accelerations which jointly with the forward create a periodic change in micro-g-forces on board the unmanned AES. For the space vehicle of the examined type, the levels of computed micro-g-forces are the limit for the weightlessness state which could be feasible in practice.

A periodic change in the mass force can have a significant effect on the convective and hydrostatic processes in weightlessness which is illustrated by numerical calculation of the Navier -Stokes equation in the Boussinesq approximation for a germanium melt.

SECTION 2. CONVECTION, HEAT AND MASS EXCHANGE /27

2.1. Vibration Thermal Convection in a Closed Region in Weightlessness

G. Z. Gershuni, Ye. M. Zhukhovitskiy, Yu. S. Yurkov (Perm')

An examination is made of the vibration thermal convection of a viscous incompressible liquid in a closed space in weightlessness. Convection is caused by an averaged mass force which emerges in a nonuniformly heated liquid when there are high frequency vibrations. A previous [1, 2] study was made of certain equilibrium configurations and their stability was studied. This work studies the developed vibration convection which emerges under conditions where equilibrium is impossible. A system of nonlinear averaged equations of vibration convection which is numerically solved by the grid method is used to describe the averaged motion and the associated heat transfer.

The planar problem of vibration convection is solved in a rectangular region with length to width ratio of L. The vibration axis is parallel to the two long sides which are maintained with different constant temperatures. The temperature changes by linear law along the face sections of the boundary. All the boundaries of the rectangular region are considered solid. The problem parameters are: vibration number of Rayleigh R defined through the difference in boundary temperatures, thickness of the layer and vibration parameter; Prandtl number P and geometric parameter L.

The calculations show that with small Rayleigh numbers, regardless of the values of the other parameters, weak averaged

convective flow of a four-vortexstructure develops in the cavity which is due to the disorder in the strict mechanical equilibrium conditions. With an increase in R, this flow loses stability and a transition to a new flow mode occurs; the structure of the branched flow and the critical R number depend on L. /28

With L about 1 (region close to a square), the secondary flow differs from the main because of the presence of a connector which connects the pair of diagonally arranged vortexes. The primary motion in the supracritical region is metastable. With large L (calculations made all the way to L = 16), the secondary flow has a cellular structure, and the transition point is close to the critical point for loss of stability in equilibrium in an infinite flat layer with longitudinal vibration axis. Characteristics of flow and heat exchange are presented and discussed. Asympototic laws for heat transfer are obtained for the given layer and the square in the form of dependends of the Nusselt number on R. With all L, the crisis of main flow is slight and is accompanied by an increase in the transverse heat flow. In the example of the square region (L = 1), the effect of the Prandtl number on the characteristics of vibration convection is clarified.

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2.2. Electroconvective Heat Exchange

M. K. Bologa, I. A. Kozhukhar', O. I. Mardarskiy, I. V. Kozhevnikov (Kishinev)

Control of the convective heat exchange processes, orientation and pumping of dielectric liquids in weightlessness can

occur with the help of an electrical field. It is common knowledge that application of an electrical field to a slightly conducting liquid results in the development of macroscopic motion in it which has been called electrical convection. The latter is observed in homogeneous and heterogeneous mobile media (liquids, gases, emulsions, etc.) and is used in different areas of technology. This report presents the results of studying /29
electroconvective (EC) heat exchange, EC-pumps and heat exchangers.

The relationships of heat output with low temperature pressures indicate the significant role of the isothermic mechanism for electrification of a medium which was taken into consideration in generalizing the experimental data.

With partial filling by liquid of the interelectrode space of a capacitor, the process of liquid dispersion is observed. A relationship is found for the coefficient of heat output in condensation and evaporation of the sprinkled liquid film with dispersion in an electrical field, which takes into consideration its thickness defined by the equilibrium condition for the electrostatic pressure forces and surface tension.

The pressure-flow characteristics of liquid EC-pumps are defined on the assumption of "frozen" free charges and with consideration for the effect of the latter on the distribution of the potential in the interelectrode gap. The maximum pressure is determined respectively for the one-dimensional, cylindrical and spherical symmetries.

A number of heat exchangers used for cooling radio electronic apparatus are developed based on EC- effects.

2.3. Quality Questions in the Theory of Thermocapillary Motion

B. K. Kopbosynov, V. V. Kuznetsov, V. V. Pukhanchev (Novosibirsk)

1. The problem of liquid film motion on a solid plane under the influence of thermocapillary forces is examined in the

framework of the theory of thin layer. It turns out that the transverse thermal flux from the gas phase into solid results in spread of the film. In planar and axisymmetrical cases, with n increase in time the motion enters a self-modeling mode. If the thermal flux has the opposite direction, then the film loses its stability.

2. A study was made of the asymptotics of the planar stationary thermocapillary motion near the contact point of the liquid, gas and solid. If the contact angle is smaller than a certain critical value which depends on the Marangoni number, then the flow consists of a series of vortexes of diminishing dimensions and intensity as the contact point is approached. /30

3. Calculations were made in a quasistationary approximation for the thermocapillary drift of a spherical bubble in a melt of different metals. The melt boundary is assumed to be spherical or flat, and distribution of temperature is assigned on it depending on time. Based on calculations, evaluations were obtained for purifying the melt from gas bubbles in weightlessness.

4. Marangoni equations of boundary layer were studied for axisymmetrical stationary motion in weightlessness. In contrast to a planar case, the longitudinal pressure gradient here is not negligible; it is associated with the shape of the free surface which is also subject to determination. Theorems were obtained for existence and uniqueness of solving the developing problem with free boundary.

5. An asymptotic plan was proposed for stationary convection in a column of liquid whose lateral surface is free, and the ends are flat solid surfaces whose temperature is constant, but varying. With a large temperature gradient, the flow consists of a set of Prandtl, Marangoni boundary layers and angular boundary layers which join with each other and the flow nucleus. The axisymmetrical circulation flow in the nucleus is computed

on the basis of the Bachelor - Lavrent'yev mode which is generalized for the case of nonisothermic motion.

6. A class of invariant and partially invariant solutions to the thermocapillary motion equation is described. The solution to the two-dimensional nonstationary problem regarding thinning of the liquid film restricted by parallel flat free surfaces where the temperature along them has a quadratic dependence on the distance to the symmetry axis is examined as an example.

2.4. Thermal Gravitational - Capillary Convection in a Rectangular Plan /31

V. S. Berdnikov, A. G. Zabrodin, V. A. Markov, V. I. Panchenko (Novosibirsk)

Experimental studies were conducted of thermal gravitational-capillary convection of liquid (ethyl alcohol $Pr \approx 14 - 17$; glycerine $Pr \approx (1 - 12.5)10^3$) in rectangular plans with dimensions: height $H = 72.5$ mm; length $L = 144$ mm, width $D_1 = 5$ mm, $D_2 = 30$ mm. The two vertical walls of the cavity ($D \times H$) are copper and are heated to different temperatures (T_1 and T_2). The other surfaces of the cavity are organic glass. The upper liquid boundary can be free (in certain experiments, above the organic glass cover). The experiments vary the height of the liquid layer h ($3 \text{ mm} \leq h \leq 72.5 \text{ mm}$) and temperature gradient $\Delta T = T_1 - T_2$. There is a corresponding variation in the ratio between the Grashof numbers $Gr = (\beta g/\nu^2)(\Delta T/L)h^4$ which characterizes the contribution of the thermogravitational forces to the formation of convective flow, and Marangoni numbers $Ma = (-\partial\sigma/\partial T)(\Delta T/\rho\nu^2 L)h^2$, characterizing the contribution of thermocapillary forces. The evolution of the spatial form of convective flow is traced in a broad interval of Gr and Ma numbers. Measurements were made of the velocity and temperature fields. A study was also made of the gravitational and capillary flow in the plane with $D_2 = 30$ mm with isothermic (hot) side walls and cooler placed in the center of the cavity on the free surface of the liquid with dimensions on the horizontal

l = 22 mm. Studies were made in the layer height range 8 mm $\leq$ h $\leq$ 72.5 mm; 2°C $\leq$ ΔT $\leq$ 40°C.

2.5. Numerical Modeling of the Crystallization Processes with Convection

B. I. Myznikova, Ye. L. Tarunin (Perm')

2.6. Gravitational and Nongravitational Mechanisms for Mixing a Melt in the Chokhral'skiy Method /32

V. I. Polezhayev, A. I. Prostomolotov (Moscow)

The Chokhral'skiy method of extension from a melt is the most widespread method for producing three-dimensional monocrystals under terrestrial conditions, therefore it is very important to study the possibilities of improving it in weightlessness. The flow plan in the melt in this method is extremely complicated and includes interaction of the mechanisms for motion of varying nature (rotation of a crystal and crucible, thermal, concentration and thermocapillary convection, etc.).

This report examines the question of the contribution to the resulting melt motion of individual mechanisms of convection and studies the mixing features which can occur when the crystals are grown by this method in weightlessness.

The study was made based on numerical solution to nonstationary Boussinesq equations for axisymmetrical motion of the melt in the crucible when there is rotation of the crystal and the crucible. An examination is made of the admixture distribution with isothermic motion of the melt (separate and counterrotation of the crystal and the crucible), effect of thermal gravitational, thermocapillary convection and mixing of the melt when there is no thermal gravitational convection. The diffusion - thermal model of heat and mass exchange in a crucible was examined for comparison; advantages and shortcomings of mixing when crystals are grown from the melt in weightlessness are discussed.

2.7. Interaction of Fluxes Caused by Thermocapillary Convection and Rotation in Zonal Melting, and Their Effect on Admixture Distribution

Ye. D. Lyumkis, B. Ya. Martuzan, E. N. Martuzane (Riga)

Numerical methods were used to study fluxes in the liquid zone during zonal melting of different materials by solving motion /33 equations of a viscous incompressible fluid. Based on the values found of the component of melt motion velocity, admixture distribution in the melt zone is found from a solution to the convective diffusion equation.

A liquid cylinder that is restricted from the top and from the bottom by solid discs is examined as a model of the liquid zone. The discs can rotate. Heating is done by heat source (high - frequency inductor, electron beam) which is symmetrical in relation to the middle of the zone plane.

As the calculations show, a determining factor of motion for the examined process is thermocapillary convection, in this case not only in weightlessness, but also with normal gravitational force. With small temperature differentials, two vortexes are formed in the liquid zone, and with large gradients, four: two near the surface, and two near the axis of the liquid zone. Inclusion of rotation in the examination results in a change in the configuration of the vortexes governed by thermocapillary convection, but complete elimination of these vortexes, if it is attained, occurs with comparatively large values for the disc rotation rate.

From the viewpoint of technology, it is very important to clarify the nature of admixture distribution depending on the conditions for growing crystals. Analysis of the hydrodynamic fluxes explains a number of admixture distribution features in the grown monocrystal. Thus, the presence of a cylindrical layer enriched (depleted) with admixture can be explained by the presence

of four vortexes in the zone which entails the appearance of a maximum axial velocity near the crystallization zone that is located roughly at a distance of three-fourths of the radius from the axis. A qualitative comparison is made of the computation results with the experiment.

2.8. Optimizing the Monocrystal Growth Conditions with Regard for Melt Hydrodynamics

V. E. Distanov and B. G. Nenashev (Novosibirsk)

This work examines questions of growing crystals by the Bridgeman - Stokbarger method using forced mixing of the melt. /34
The crystallization process occurs under conditions where the effect of the thermal gravitational forces is considerably lower than the centrifugal forces that develop during modulated rotation of the ampoule with the melt. An experimental relationship was obtained between the optical quality of the crystals and the similarity criteria which characterize this process (for example, the Taylor number). This link together with other relationships of the growth conditionsof quality criteria type permits selection of the optimal conditions for growing high quality monocrystals; it helps to understand the processes occurring in the melt, and their effect on the perfection of the crystal structure.

S2.1. Nonstationary Heat Exchange in a Cylindrical Cavity When There Is Vibration Convection

G. Z. Gershuni, Ye. M. ZHukhovitskiy, V. I. Chernatynskiy, A. N. Sharifulin (Perm')

A numerical study is made of the nonstationary vibration convection in an infinite cylinder of round section. The cylinder together with the liquid filling it makes high - frequency harmonic vibrations along a direction perpendicular to its axis. Until the initial moment in time, the liquid in the counting system connected to the cylinder is at rest and has a uniform

temperature. At the initial moment, the boundary temperature suddenly rises and is futher maintained constant.

A system of averaged equations of vibration convection is used to describe the convective flow and heat transfer during the nonstationary process of heating. The planar problem is solved by the grid method. A study was made of the evolution of the velocity and temperature fields. The presence of vibration convection results in considerable intensification of the heating process and reduction in its characteristic time as compared to the case of pure heat conductivity.

A more general statement of the tasks corresponding to the heating process under such conditions where convection governed /35 by the static gravitational field occurs is also examined.

S2.2. Stability of Plane - Parallel Vibration - Convective Flow
G. Z. Gershuni, Ye. M. Zhukhovitskiy, A. I. Ponomarchuk, V. M. Shikhov (Perm')

An examination is made of plane - parallel convective flow in a flat infinite layer in weightlessness due to high -frequency harmonic vibration, whose axis is directed along the layer. The temperatures are assigned on the layer boundaries $T_1 = Az + \theta$ and $T_2 = Az - \theta$; thus in each section of the layer there is a constant temperature difference 2θ, and, in addition, there is a constant temperature gradient A which is directed along the vibration axis z.

In the closed layer under these conditions of heating plane - parallel vibration - convective flow is possible with odd profiles of velocity and temperature [1]. Stability of this flow was studied in relation to the small normal perturbations. The method of Galerkin and the method of by-step integration was used to solve the spectral amplitude task. The stability boundaries and the characteristics of critical perturbations were determined depending on the task parameters.

Different planar models of instability are isolated. It is indicated, in particular, that the main flow reveals monotonic instability in relation to the perturbations of hydrodynamic type linked to the development of vortexes on the boundary of counter fluxes. The stability boundary is determined by the critical Grashof number which is defined through the cross difference in temperatures and the vibration parameter. This critical G_m number depends on the dimensionless longitudinal gradient R. With small and large R, the flow is absolutely stable; destabilization occurs in the intermediate region.

Instability associated with development of wave (temperature) perturbations is also found with definite parameter values. It /36
is demonstrated that the spatial spiral perturbations are always damped.

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S2.3. Vibration Thermal Convection in a Square Cavity in Weightlessness with Random Frequencies

Yu. S. Yurkov (Perm')

A study was made of the vibration thermal convection in a cavity of square section that is filled with incompressible liquid and makes harmonic oscillations along a certain axis in weightlessness. The boundaries of the cavity that are parallel to the vibration axis are maintained with constant different temperatures; the temperature changes according to a linear law on two perpendicular sections.

Complete equations of vibration convection in variables of the current, vortex and temperature function were used to describe the convective motion. The task contains three dimensionless parameters: Grashof number G defined through the amplitude of vibration accelerations and difference in the temperatures of the boundaries, Prandtl number P and dimensionless

frequency ω. The numerical solution was found by the grid method. An explicit plan and plan of longitudinal - transverse trial run were used. The main calculations were conducted on a 25 x 25 grid for average frequencies and 35 x 35 for high vibration frequencies.

After the transitional process of development of introduced initial perturbation in the liquid, regular convective oscillations were established in which all the local and integral characteristics of the velocity and temperature fields oscillate around certain average values with rotation frequency ω. The main characteristics that were observed were the value of the current function $\bar{\psi}_{cp}$ that was average for the cavity and averaged in time, as well as the "input" thermal flux $\bar{N}$ that was averaged for the modulation period. Dependences of these quantities on the task parameters are presented and discussed; the structure of the convective fluid oscillations is clarified.

The calculations indicated that there is an area of parameters $\varepsilon = G^2/2\omega^2$ and ω in which symmetrical sign-variable motion occurs with $\bar{\psi}_{cp} = 0$. Beyond the limits of this region, this motion loses stability and flow develops with dominant direction of circulation ($\bar{\psi}_{cp} \neq 0$). In this case (depending on the initial conditions) two branches can develop which differ only in the sign $\bar{\psi}_{cp}$. With high vibration frequencies, the only determining parameter of the task (except the Prandtl number) becomes ε. The results of the calculations for this region agree with those previously obtained [1] based on averaged equations for the vibration convection.

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S2.4. Vibration Convection in Cylindrical Layer in Weightlessness

A. N. Sharifulin (Perm')

A study is made of vibration convection of a viscous incompressible liquid between infinite coaxial circular cylinders. The cylinders are maintained at constant different temperatures and make high - frequency harmonic oscillations along the direction perpendicular to their axis. The averaged equations of vibration convection are used to describe the flow. The parameters of the task are the Grashof vibration number S which is defined through the thickness of the layer and the difference in temperatures between the cylinders, the Prandtl number and the ratio of the radius of the external cylinder to the radius of the internal ρ.

With small values of S, the planar problem is solved analytically by the method of small parameter. The solution is presented in the form of an expansion for S; zero and first terms are found (using convective flow). It was found that the structure of the flow significantly depends on the geometric parameter ρ. With $\rho > 4.77$ (thick layer), the averaged flow has a four - cell structure. With $\rho < 4.77$, the flow acquires a two - level structure along the radius, and eight vortexes develop in the layer. /38

With random S, the solution is numerically found on a computer using the finite differential method. The findings are in good correspondence with the solution obtained analytically for small S. Data are presented on the effect of the averaged convective flow on heat exchange between the cylinders. Patterns were obtained for flow and the temperature field for different values S and ρ.

S2.5. Stability of Convective Motion in Flat Layer in a Vibration Field

A. N. Sharifulin (Perm')

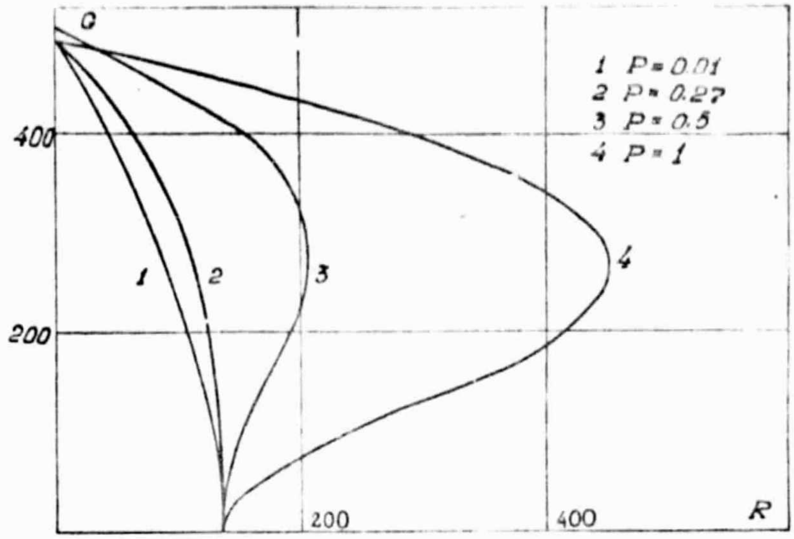
A vertical flat layer of viscous incompressible liquid that is bounded by solid parallel planes maintained with constant and different temperatures is examined. The layer as a unit makes

high - frequency harmonic oscillations in a vertical direction. In order to describe motion of the liquid, averaged equations of vibration convection are used. The determining parameters of the task are: G--Grashof number, R--Rayleigh vibration number, P--Prandtl number. The Grashof number was defined through acceleration of free fall, and the Rayleigh vibration number was defined through the vibration parameter. The half width of the layer and the half difference in temperatures between the walls were selected as the unit of length and temperature. With these conditions, an averaged plane - parallel flow develops with cubic profile of velocity and linear temperature distribution. A study was made of the stability of this flow in relation to the small normal perturbations. The boundary value problem for amplitudes of flat perturbations was solved numerically by the method of Runge - Kutt - Merson. /39

In the limiting case of the lack of vibrations $R = 0$, the problem becomes the well-studied problem of stability of convective flow with cubic velocity profile. Another limiting case of $G = 0$ corresponds to the problem regarding stability of the condition of averaged equilibrium in weightlessness. As indicated in [1, 2], this equilibrium becomes unstable when the parameter R reaches the critical value $R_c = 133.3$.

The figure presents the characteristic stability diagrams in relation to the monotonic perturbations in the general case of $G \neq 0$ and $R \neq 0$. The stability areas are arranged to the left ofthe corresponding curves.

With all values of the Prandtl number $0 < P \leq 20$, the vibrations have a destabilizing effect on the stability of the main flow. On the other hand, the low gravitational force ($G < 270$) has a different effect on the manifestation of the mechanism for vibration instability. With $P < 0.27$, when there is low gravitational force, the vibration instability develops with smaller R than in the case of complete weightlessness, and with $P > 0.27$



with large values of R.

Using the similarity transformation which reduces the boundary value problem for spatial perturbations to the boundary value problem for flat perturbations, it is indicated that for all values of the Prandtl number $0 \leq P \leq 20$, the flat perturbations are more dangerous. /40

Results are presented from studying stability in relation to the oscillating perturbations.

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S2.6. Vibration Convection in Weightlessness

S. M. Zen'kovskaya (Rostov-na-Donu)

The development of convection in liquid under the influence of vibration in weightlessness was studied. On the assumption that the frequency of oscillations is great, the method of averaging is used in a form developed in the publications of

I. B. Simonenko and the author to solve the problem of the effect of vibration on convective instability in the gravitational force field.

As the main example, a case is examined where the fluid is in a flat infinite layer that is restricted by solid walls on which constant temperature is maintained. A study is made of the effect of the direction for the effects of vibration on the development of convection in weightlessness. It is indicated that if vibration is oriented transverse to the layer, then convection does not develop. In all other cases, the vibration forces cause convection in the nonuniformly heated liquid in weightlessness. A calculation was made of the relationships between the critical parameter values.

In addition, the case of binary mixture is examined.

S2.7. Convection in a Rotating Liquid Layer /41

S. Ya. Gertsenshteyn, A. I. Rakhmanov, Ye. B. Rodichev, V. N. Semin, V. M. Shmidt (Moscow)

Convection in a flat layer of uniform liquid or solution which rotates in relation to the vertical or horizontal axis is examined. The problem is studied in the framework of two - dimensional and three - dimensional transient equations of Navier - Stokes in the Boussinesq approximation [1].

When a horizontal layer rotating in relation to the vertical axis is studied, primary attention is focused on the phenomenon of sudden "spasmodic" reconstruction from the laminar periodic mode of motion to the irregular stochastic. The solution is constructed using the Bubnov - Galerkin method: the Fourier series are used in the horizontal directions, and the trigonometric functions or the Chebyshev polynomials with the corresponding weight are used in the vertical (transverse to the layer). It is significant that in this case the nonlinear interaction of the different - scale perturbations is taken into consideration (for

example, normal convective shafts with large - scale perturbations).

The conducted numerical experiments indicated, in particular, the important role of the "prehistory" of the flow (that is, the initial data of the task): with low initial amplitude of perturbations, the solution can enter a periodic motion mode, and starting from a certain fairly large initial amplitude (amplitude of "capture"), it enters an irregular stochastic mode. The solution in this case actually falls in the "region of attraction" of the so - called "foreign" or stochastic attractor. At the same time, the basic possibility of formation is explained with the same "external" parameters of the problem (Rayleigh, Prandtl numbers, etc.) of qualitatively different states of motion: either laminar or stochastic. Similar phenomena were observed, for example, in the experiments of Yu. N. Belyayev and I. M. Yavorskaya, V. S. L'vov et al. We note that with a change in the "external" parameters of the task (for example, the Rayleigh number), with fixed small initial amplitudes of perturbations and a certain specific value of the "external" parameter, there can be a drop in the normal periodic mode into the zone of "capture" of the stochastic attrac- /42
tor, and at the same time, sharp "spasmodic" reconstruction of the motion type.

Specific calculations were made both for the uniform liquid and for the binary mixture; the parameters of the task in this case corresponded to the melts of liquid metals.

In examining the flat layer of liquid that rotates in relation to the horizontal axis, central attention was focused on studying the stabilizing effect of this rotation, and to a certain extent, modeling of weightlessness. Solution to the problem was constructed in this case using the averaging method [2]. It was shown, in particular, that increase in the rotation rate in relation to the horizontal axis has a stabilizing effect and results in a decrease in the characteristic wave numbers.

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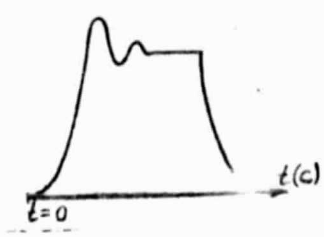
S2. 8. Experimental Modeling of Convection in Weightlessness

S. V. Zorin and G. F. Putin (Perm')

Study of convection in the variable force field is important since under conditions close to weightlessness, the oscillating component becomes dominant; in addition, vibrations can influence the modes of equilibrium and flow. Realization of the oscillating fields of large amplitude using vibration stands is only possible at high frequencies. This work suggests a method which guarantees in the convection tasks those oscill ions in the region of randomly low frequencies f, starting from 1 sec^{-1}, and consisting of rotation in a static gravitational field $\vec{g}$ of a slit cavity (long channel) with longitudinal temperature gradient ∇T around the horizontal axis lying in its plane. The method is governed /43 by the fact that in the narrow cavities, the variable rotation attracts all the liquid and does not form near - wall layers and a fixed nucleus; in the layers with longitudinal gradient, the movements are the same with vertical and inclined orientation, and the inclination is reduced to introducing the effective field g sin α along the layer (α--angle of inclination of the layer to the horizontal); adequate flows which have another appearance and develop with a $\approx$ 0 are weak so that the horizontal position models the conditions of weightlessness for the main motion. Finally, rotation should be slow in order for the centrifugal and Coriolis fields and viscous flows at the moment of acceleration and stopping to be small.

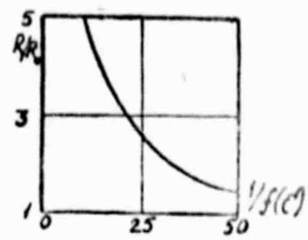
The applicability of the method is illustrated on the convective loop, two parallel channels filled with transformer oil

and closed on the ends with cross section 6.4 x 8.1 mm^2 and length 155 mm in a metal block with uniform gradient of temperature along the channels. The flows were recorded by thermocouples that were inserted into the channels. For observation, one of the walls was replaced by glass, and visualizing particles were added to the liquid. In a static case with vertical orientation of the channels that corresponds to heating from above, the equilibrium is stable; with heating from below, starting from the critical Rayleigh number R_o = 30 (R_o number is defined through $\vec{g}$, ∇T and the average half width of the channel), stationary closed circulation is developed, the liquid is lifted in one of the channels and is lowered in the other. This circulation is maintained with inclination in relation to the horizontal small axis of symmetry all the way to the 10° angle.



Rapid rotations of the model from the horizontal to vertical position which corresponds to heating from below, and back, model the development of convection in the temperature-stratified liquid with momentary appearance and disappearance of the gravitational field g. The dependence of circulation amplitude on time t for $R = 2.8\ R_o$ indicates that after inclusion of the field (t = 0), there is an exponential rise in the circulation to amplitudes which are 90% of the stationary. Emergence onto a stationary value oscillates. In the region $R \lesssim 4R_o$, the exponent equals 0.03 $(R/R_o - 1)$. Convection damping begins immediately after inclusion of the field and is described by an exponent. /44

Periodic turning of the model from one vertical position to another simulates the situation where the model is fixed, and the gravitational field on the background of weightlessness in turn adopts the values $\pm\ \vec{g}$, where $\vec{g}$ is directed along the channels.



The chart at coordinates R/R_o, f shows the neutral curve R_f, separating the region of stability from the upper region where convection is excited if only on part of the period. If $R < R_o$, the equilibrium is stable at all frequencies. When $R \geq R_o$, with low -frequency oscillations, a quasistationary mode is observed. Circulation reaches a value which corresponds to the static field, where $\vec{g}$ and ∇T are antiparallel. In a high -frequency force field, equilibrium is disrupted with significantly large R, and the intensity of circulation fluctuates in the phase with the field: circulation rises where $\vec{g} \parallel \nabla T$, and drops to zero in another half - period.

S2.9. Deformation of Free Liquid Surface by Thermocapillary Motion

A. F. Pshenichnikov and G. A. Gokmenina (Perm')

An experimental study was made of thermocapillary convection in a thin horizontal layer of liquid poured into a nonisothermic vessel. The working liquids used were ethyl alcohol, acetone, kerosene and water. The surface relief was studied using a short-focus schlieren system and optical cathetometer KM - 6. The temperature measurement was made using copper - constantan thermocouples.

It was found that the development of thermocapillary convection is always accompanied by a considerable deformation in the free surface. The uniform horizontal temperature gradient causes a flat stationary movement in which the thickness of the liquid layer changes with the coordinate by the root law. Liquid motion /45

around the concentrated heat source which is located in the center of the vessel has axial symmetry. A basin forms on the surface of the liquid above the heat source. With a temperature difference of several tens of degrees, the depth of this basin can reach 1 mm. Cooling of the vessel center results in the corresponding increase in the thickness of the liquid layer in this region. If the thickness of the layer does not exceed 0.5 - 0.7 mm, then regardless of the heating conditions, it is possible to expose the heated sections of the vessel bottom. In this case, the liquid is collected in the form of drops above the cooled sections.

The gravitational force is the main reason which prevents the deformation of the free liquid surface. Therefore under conditions of reduced gravity, the effect of thermocapillary convection on twisting of the free surface should be considerably greater.

S2.10. Ground Modeling of Thermocapillary Drift of Bubbles in Weightlessness

V. A. Briskman and A. L. Zuyev (Perm')

A study was made of the thermocapillary drift of gas bubbles in a nonuniformly heated liquid that develops because of the dependence of the surface tension coefficient on temperature. This phenomenon is manifest, in particular, in the production processes in space. In the pure form, thermal drift can be implemented only in weightlessness, and on Earth is suppressed or complicated by side effects associated with the effect of the gravitational force (gravitational convection, Archimedes forces, etc.). This report proposes techniques for ground modeling whose essence is weakening of the effect of side phenomena to a level which corresponds to the conditions close to weightlessness. In this case procedures are used which reduce the Rayleigh number, and consequently, the intensity of convection with preservation of a sufficient quantity of thermocapillary forces.

The authors previously published the results of preliminary experiment which confirmed the existence of thermal drift [1]. The report presents quantitative results of experiments in three variants: a) with heating from the top; b) in thin layers of different liquids; c) in water at temperatures close to 4°C-- point of inversion of the coefficient of volumetric expansion. Side effects were directly measured which made it possible to establish the limits of applicability of each experimental method. Trajectories and velocities of the thermal drift were determined. Measurements with accuracy about 10% correspond to the analytical theory [2] and numerical calculations [1] which refer to conditions of weightlessness and take into consideration the nonlinear effects associated with bubble deformation. In the linear approximation, the dimensionless values of drift velocity equal half of the Marangoni number.

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S2.11. Bubble Drift in Heterogeneous Field of Volumetrically Soluble Surfactant

D. A. Kazenin and V. N. Mankevich (Moscow)

Tangential stresses on the interphase surface with heterogeneous distribution of surface tension can serve as the only reason for the development of relative motion of phases in weightlessness. In an isothermic case, heterogeneity of the surface tension is determined by heterogeneity of distribution of the adsorbed surfactant over the interphase surface. In the case of the volumetrically dissolved sufactant, the problem is complicated by

diffusion kinetics of mass exchange between the adsorption layer and the surfactant solution with spatially nonuniform distribution of the concentration,as well as the adsorption dynamics.

Assume that the bubble with surface Σ drifts in an infinite solution massif with velocity $\vec{U}$. The shape of the surface and the drift velocity must, generally speaking, be determined by solving the task. We will write the equations for distribution of velocities $\vec{V}$, pressure p and concentrations in a mobile counting system which coincides with the momentary position of the center of mass of the moving bubble:

$$\rho \frac{\partial \vec{V}}{\partial t} + \rho(\vec{V}\nabla)\vec{V} = -\nabla p + \mu \nabla^2 \vec{V}; \quad \nabla \vec{V} = 0; \qquad (1)$$
$$\frac{\partial c}{\partial t} + \vec{V}\nabla c = D\nabla^2 c.$$

At a distance from the bubble, the condition of nonperturbation of the velocity field and the known gradient of concentration are assigned

$$\vec{V}|_{z\to\infty} = 0; \qquad \nabla c|_{z\to\infty} = \vec{E}. \qquad (2)$$

The collinear vectors $\vec{E}$ and $\vec{U}$ in space determine the axial symmetry of the task. The symmetry axis passes through the center of mass of the moving bubble. The kinematic condition of continuous streamlining is assigned on the surface of the bubble

$$(\vec{V}|_\Sigma \cdot \vec{n}) = -(\vec{U}\cdot\vec{n}), \qquad (3)$$

the dynamic conditions

$$\sigma_{n\theta}|_\Sigma + \frac{\partial \sigma}{\partial \Gamma}\frac{1}{\sqrt{g_{\theta\theta}}}\frac{\partial \Gamma}{\partial \theta} = \sigma'_{n\theta}|_\Sigma ; \qquad (4)$$

$$\sigma_{nn}|_{\Sigma} + 2H\sigma = \sigma'_{nn}|_{\Sigma} \tag{5}$$

and condition which describes the flow of surfactant from the volume to the surface

$$D(\nabla c|_{\Sigma} \cdot \vec{n}) = q. \tag{6}$$

Here θ--angle between the radius - vector of the point on the surface and the symmetry axis; H and $g_{\theta\theta}$--average curvature and one of the components of the metric tensor of the surface Σ which can be expressed through the coefficients of the first two main quadratic forms; σ and Γ--dynamic surface tension and dynamic adsorption. In addition, conditions should be assigned which describe the dynamics and the kinetics of adsorption of surfactant on the surface Σ, and namely

$$\frac{\partial \Gamma}{\partial t} + \nabla_{\Sigma}(\Gamma \vec{V}) = D_{\Sigma} \nabla^2_{\Sigma} \Gamma + q; \tag{7}$$

$$q = \beta\left(1 - \frac{\Gamma}{\Gamma_{\infty}}\right) c|_{\Sigma} - \alpha\Gamma. \tag{8}$$ /48

Here Γ_{∞}--maximum adsorption, β and α--kinetic coefficients of adsorption and desorption respectively.

Finally, a condition must be assigned from which the steady -state drift velocity is defined (integral condition of equality to zero of the total force acting on the bubble where the force element equals the internal product of the stress tensor on the vector of the surface element Σ)

$$\oint_{\Sigma} \{\sigma_{ik}\} d\vec{\Sigma} = 0.$$

If the shape of the surface Σ is considered to be a priori assigned, then one of the conditions (5) and (9) is surplus.

In conclusion, main terms in the expansion for small Marangoni numbers $(\rho\beta R^2 E|\partial\sigma/\partial\Gamma|/(\alpha\mu^2) \ll 1$ of the solution for the stationary problem on slow drift of a hollow spherical bubble of radius R in a diluted surfactant solution $(\Gamma/\Gamma_\infty \ll 1)$ are presented as an example.

S2.12. Effect of Thermocapillary Convection on Thermal Output in Slits

Yu. B. Sklovskiy (Khar'kov)

A nonuniformly heated liquid which is in contact with vapor or gas in weightlessness will make convective movements under the influence of thermocapillary forces. The experimental study of this phenomenon under real conditions is associated with considerable technical complexities. One can therefore only indicate a small number of publications [1, 2] in which thermocapillary convection is observed in a liquid in practical weightlessness, and analytical methods of study are advanced to the forefront.

An examination is made of the numerical solution to a sytem of two - dimensional equations of stationary thermocapillary convection in a rectangular channel with flat free surface.

The computation procedure and certain results are described /49
in detail in [3 - 5]. The structure of the computed convective movements is mainly determined by the ratio of the rectangle sides. The nonlinear effects influence the intensity of the vortex flows and slightly change their structure. The most intensive movement of liquid occurs at the free surface, and with an increase in the Marangoni number, only the upper vortex has a significant effect on temperature distribution. Therefore in the deep channels, breakup of the flow into individual vortexes of low intensity does not have a noticeable effect on the temperature field, and already with ratio of depth to width of 2 : 1,

the channel can be considered a slit of infinite depth.

The computed flow profiles are similar to those which the authors [2] visually observed, although the geometry of the vessel and the heat conductance conditions differed. This confirms the definitive role of surface tension gradients in forming the movement of a nonisothermic liquid in weightlessness.

It is consequently important to evaluate the effect of thermocapillary flow on heat transfer as compared to conductive heat transfer, i.e., in the absence of convection.

Quantities were found for the average Nusselt numbers on the heat - emitting surfaces depending on the value of the Bio number on a free liquid surface. Heat output rises on the "hot" wall with a rise in the Bio number and drops on the "cold" wall, since with an increase in the Bio number heat output intensifies through the interface into the region occupied by steam. In addition, circulation of liquid results in a decrease in the temperature stratification along the vertical and average interface temperature as the Bio number rises.

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S2.13. Numerical Study of Thermocapillary Convection in Weightlessness

A. A. Nepomnyashchiy, I. B. Simanovskiy (Perm')

A study was made of thermocapillary convection in the absence of gravitational forces in a cavity of rectangular cross section filled with two different viscous immiscible liquids. Two heating variants are examined: in the first case the temperature gradient is directed along, and in the second, transverse to the liquid interface. Complete nonlinear convection equations are written in variables of the current - velocity vortex function for each liquid. On the interface which is assumed to be flat and non-deformable, conditions where the normal velocity components equal zero, and there is discontinuity of temperature, heat fluxes and tangential velocity components are fulfilled. The thermocapillary effect is taken into consideration in the boundary condition for the tangential stresses.

The problem is solved by the grid method. An explicit plan is used for the method of establishment with central differences described in [1]. The Poisson equations for both liquids are solved by the iteration method. The main calculations were made on a 16 x 32 grid, and the verification tests were made on a 20 x 40 grid.

When there is a temperature gradient along the interface, movement develops in the cavity with any values of the Marangoni number. The structure of the finite - amplitude convective flows is defined. Dependences are constructed for the maximum value of the current function on the Marangoni number and the ratio of cavity sides. In the case where the temperature gradient is directed transverse to the interface, convection develops when the Marangoni number exceeds a certain critical value. The nature of flow in the supracritical region is defined for different liquid parameters. /51

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S2.14. Parametric Study of Thermocapillary Convection

K. G. Dubovik (Moscow)

Using the numerical technique [1], a parametric study was made of thermocapillary convection in a square region with isothermic walls and insulated ends. The study was made with a change in the Marangoni number in the range $Mn = 1 - 10^4$, Prandtl number $Pr = 0 - 10^2$. The obtained solutions are compared with the results of [2]. Data are presented on the intensity of movement depending on the Prandtl number, integral and local heat fluxes, thickness of the dynamic boundary layer on the free surface.

It was found that the dynamic boundary layer becomes thinner as the Prandtl number increases and the intensity of movement in the region rises. With Marangoni number of $Mn \geq 10^3$, flow reconstruction begins: the vortex center is shifted from the cold to the hot wall. This is associated with formation of a thermal boundary layer on it.

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S2.15. Certain Analytical Solutions to the Problem of Marangoni Convection in a Flat Melt Layer with Two Free Boundaries in Weightlessness /52

V. P. Shalimov (Moscow)

The problem of thermocapillary convection in a flat melt layer with two free boundaries is examined in weightlessness with regard for the crystallization front that moves at a constant rate. Determination of the velocity field with low (as compared to length) thickness of the layer uses an approximation of the boundary layer. The equations for the temperature and concentration fields in a particular case under definite conditions linking the physical parameters of the problem allow analytical solutions in the Whittaker and Bėssel functions. An analysis is made of the obtained solutions and the conditions of their applicability.

S2.16. Stability of Transient Motion of a Viscous Liquid Band with Regard for Thermocapillary Forces

V. K. Andreyev (Krasnoyarsk)

A study was made of the stability for linear approximation of motion of a viscous incompressible liquid which is described by formulas

$$u = \frac{kx}{1+kt}, \qquad v = -\frac{ky}{1+kt}, \qquad k = \mathrm{const},$$

$$\frac{p}{\rho} = -\frac{k^2 y^2}{(1+kt)^2} + \frac{k^2 \eta_0^2}{(1+kt)^4} - \frac{2\nu k}{1+kt}, \quad \eta_0 - \mathrm{const} > 0.$$

Here u, v--velocity components, p--pressure, ρ--density, ν--coefficient of viscosity; temperature T = T(y, z, t).

This solution precisely satisfies the Navier - Stokes equations and conditions of free boundaries $y = \pm\eta_0/(1 + kt)$ with random dependence of the surface tension on temperature.

Qualitative and quantitative characteristics of interface behavior linked to the effect of viscosity and thermocapillary action were obtained.

S2.17. Computation of Electroconvective Flows

A. I. Zhakin (Khar'kov)

The most popular approach to describing electrohydrodynamic phenomena in slightly conducting liquids is based on adopting the Ohm law $\vec{j} = \sigma\vec{E}$, where the conductance σ may depend on the temperature and intensity of the field [1 - 4]. However, this assumption is too approximate, since the EHD phenomena cannot be explained from it (for example, isothermic electroconvection in a flat capacitor [5], dependence of EHD flows on electrode polarity [6]), nor the diversity in the nonlinear sections of volt - ampere characteristics [7 - 9] and the ampere - time measurements [10].

The conductance of liquid dielectrics is determined by an activation mechanism (and not by a zone, as in metals for which the relationship $\vec{j} = \vec{E}$ is true), therefore the current density is determined not only by field intensity E, but by the concentration of ions q, that is $\vec{j} = bq\vec{E}$, where b--ion mobility. In a more general case, the system of equations of electrohydrodynamics has the following appearance

$$\rho_t + \operatorname{div} \rho\vec{v} = 0,$$

$$\rho(\vec{v}_t + (\vec{v}\nabla)\vec{v}) = -\nabla p + \eta\Delta\vec{v} + \left(\zeta + \frac{\eta}{3}\right)\nabla \operatorname{div}\vec{v} + \vec{f}_E,$$

$$\vec{f}_E = \nabla(\rho E^2/(8\pi)(\partial\varepsilon/\partial\rho)) - E^2\nabla\varepsilon/(8\pi) + q\vec{E},$$

$$\operatorname{div}\varepsilon\vec{E} = \pi q, \quad (q = q_1 - q_2 + q_3 - q_4), \quad \vec{E} = -\nabla\Phi,$$

$$\rho T\left(\frac{dS}{dt} + \frac{d}{dt} T \frac{\partial\varepsilon}{\partial T}\frac{E^2}{8\pi}\right) = \varkappa\Delta T + \Phi',$$

$$q_{1t} + \operatorname{div}(b_1 q_1\vec{E} + q_1\vec{v}) - z_1 N_1 \mathcal{H}_1 - \alpha_1 q_1 q_2 = \Sigma_1,$$

$$q_{3t} + \operatorname{div}(b_3 q_3\vec{E} + q_3\vec{v}) - z_3 N_2 \mathcal{H}_2 - \alpha_2 q_3 q_4 = \Sigma_2,$$

$$-q_{2t} + \operatorname{div}(b_2 q_2\vec{E} - q_2\vec{v}) = -\Sigma_1; \; -q_{4t} + \operatorname{div}(b_4 q_4\vec{E} - q_4\vec{v}) = -\Sigma_2,$$

$$S = S(\rho, T), \quad p = p(\rho, T), \quad \varepsilon = \varepsilon(\rho, T).$$

The boundary conditions for q_1 and q_2 are determined by injection processes on the electrode surfaces and are presented,

for example, in publication [11]. If it is known, for example, what the constants are for the rates of the oxidation reactions on the anode k_f and reduction on the cathode k_i, then on the anode: $q_1 = z_1 k_f(E) Na/b_1 E$, on the cathode: $q_2 = Z_2 k_i N_k / b_2 E$.

For densities of ions q_3 and q_4 which are formed in the volume only because of dissociation, the boundary conditions look like: on the anode: $q_3 = 0$, on the cathode: $q_4 = 0$. The other boundary conditions for $\vec{v}$, T and ψ are generally accepted.

Thus, all the phenomena associated with conductance of dielectric liquids should follow from the presented system of equations and boundary conditions.

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S2.18. Convection Coverned by Thermoelectromotive Force in Microgravitation

V. A. Saranin (Glazov)

In microgravitation, the intensity of the free thermal convection is very slight, which promotes, for example, production of materials with more advanced microstructure [1]. However, in principle, other convection mechanisms could exist, which under terrestrial conditions are suppressed by natural convection. The detection and evaluation of the effectiveness of these mechanisms is an important problem whose solution could promote forecasting of technological experiments in space [1].

An examination is made of a flat layer of liquid whose boundaries are maintained with different temperatures T_1 and T_2. It is assumed that the liquid has two different types of current carriers, and the liquid is neutral under isothermic conditions. Under the influence of the temperature gradient, a separation of charges (thermoelectromotive force develops) will take place, so that a volumetric charge and an electrical field will exist in the layer. Thus, a mechanical force will act on the element in the liquid volume. With sufficient magnitude of these forces, equilibrium can prove to be unstable in relation to the hydrodynamic perturbations.

The behavior of small perturbations was studied on the basis of linearized Navier - Stokes equations (only the Coulomb forces were considered), equations of heat transfer and both sorts of current carriers. It was found that with sufficient magnitude of dimensionless parameter

$$B = \frac{\varepsilon \alpha^2 |\nabla T|^2 d^3}{\eta \lambda}$$

(α--effective thermoelectromotive force), the equilibrium is unstable. The ratio of the B criterion to the Rayleigh number equals:

$$B/\mathcal{R} = \varepsilon\alpha^2 |\nabla T|/(\rho g \beta d).$$

Assuming that $\varepsilon \sim 10, \alpha \sim 10^{-3}$ $B/$ deg, $g \sim 10^{-5} g_0, \beta \sim 10^{-4}$ deg,$^{-1}$ $\rho = 1$ g/cm^3, we obtain $B/R \approx 10^{-3} |\nabla T|/d$ Thus, with reasonable $|\nabla T|$, the examined type of convection can be manifest only in thin ($d \approx 10^{-2}$ cm) layers of electrical conducting liquids. Similar estimates were obtained in [2].

An examination was also made of the flow of electrical conducting liquid between two parallel plates which are maintainaed at different temperatures. An external electrical field E is applied parallel to the plates. The interaction of the applied field and the volumetric charge induced by the thermoelectromotive force results in the development of convective motion. The maximum velocity of this motion

$$v_{max} \sim \varepsilon\alpha \, \Delta T \, E/\eta .$$

With E about 10 V/cm, the velocity can reach the value of about 10^{-2} cm/sec.

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S2.19. Possibilities of Modeling Central - Symmetrical Convection in Weightlessness

Yu. N. Belyayev and I. M. Yavorskaya (Moscow)

It is common knowledge that in a spherically symmetrical gravitational field, it is considerably important for basic

problems of astro- and geophysics. In all those cases where the scales of motion are comparable to the dimensions of the astrophysical bodies and the studied motion occurs in rotating systems, it is significant that convection occurs in spherical layers. New types of motion develop under these conditions which cannot be predicted from the results of studying similar motions in flat /57 layers [1]. In laboratory modeling of global phenomena in astrophysical objects it is therefore very important to reproduce the centrally - symmetrical field and use spherical layers.

Ponderomotor forces that emerge in liquid dielectrics when a heterogeneous electrical field and temperature gradient [2] are applied to them afford us this opportunity. The expression for the force then looks like [3]

$$\bar{f}_e = \frac{1}{8\pi} \nabla\left[E^2 \rho \left(\frac{\partial \varepsilon}{\partial \rho}\right)_T\right] - \frac{E^2}{8\pi} \nabla \varepsilon ,$$

where E--field intensity, ε--dielectric permeability, while ρ and T--density and temperature of liquid.

In uniform dielectrics, $\varepsilon = \varepsilon(\rho, T)$ and the lifting force in the Boussinesq approximation is presented in the form

$$\bar{f}_e' \approx \frac{\alpha \rho_0 T'}{8\pi} \nabla\left[E_0^2 \left(\frac{\partial \varepsilon}{\partial \rho}\right)_{T,0}\right] - \frac{E_0^2}{8\pi} \left(\frac{\partial \varepsilon}{\partial T}\right)_{\rho,0} \nabla T', \tag{1}$$

where the indexes o and the apostrophe refer to quiescent quantities and perturbations. When the difference in potentials and the temperature gradient are maintained between two concentric spheres, then the equilibrium distributions are

$$\bar{E}_0 = V_0 r_1 r_2 \bar{e}_r / (r_1 - r_2) r^2; \quad \nabla T_0 = -(T_1 - T_2) r_1 r_2 \bar{e}_0 / (r_2 - r_1) r^2,$$

where r_1 and r_2--radii of internal and external spheres, V_o and $(T_2 - T_1)$--differences in potentials and temperatures between the spheres. The difference in the direction of the lifting force from the radial is insignificant, since the component of electrical

force in the tangential direction of the potential and does not influence convective motion. The active acceleration looks like

$$\bar{g}_e = V_0^2 r_1^2 r_2^2 \left(\frac{\partial \varepsilon}{\partial T}\right)_{\rho,0} \bar{r}_0 / 2\pi (r_2 - r_1)^2 \rho_0 \alpha r^5.$$

The difference in radial relationship g_e and $g \sim \bar{r}_0 / r^2$ results only in certain quantitative changes in parameters; in particular, the critical value of the Rayleigh number is somewhat reduced.

It is obvious that with laboratory modeling on Earth it is necessary to fulfill the condition $g_e >> 980$ cm/sec^2. With reasonable dimensions of the unit, this results in a case of non-polar liquids in the need to use too strong electrical fields $V_0 \approx 100$ kV. In weightlessness, the condition $g_e >> g$ can easily be fulfilled. However, in studying the important case of interaction between convection and rotation, an additional restriction appears; the Froude rotational number should be small

$$Fr = \Omega^2 r_2 / g_e = 2\pi\alpha\delta^2 r_2^3 \rho_0 \Omega^2 \Big/ \left(\frac{\partial \varepsilon}{\partial T}\right)_{\rho,0} V_0^2 \ll 1, \quad \delta = \frac{r_2 - r_1}{r_1}.$$

Estimates are presented for values of the main parameters to model different convection conditions. A discussion is held of possible effects that are not taken into consideration by the linear approximation [1]. In particular, the use of the variable electrical field instead of a constant one to avoid the development of electroconvection requires an examination of different relaxation processes.

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S2.20. Electroconvective Instability of Isothermic Layer of Liquid Dielectric

V. P. Usenko, A. V. Vaysleyb (Kishinev)

An examination is made of electrification of a flat layer of isothermic slightly conducting liquid in an approximation of the Ohmic model of conductance with regard for diffusion:

$$\vec{j} = \sigma\vec{E} - D\nabla\rho, \quad \rho = \nabla\varepsilon_0\varepsilon\vec{E}, \quad \nabla\vec{j} = 0 .$$

It is indicated that in the framework of the adopted model one can describe different experimental distributions for the electrical field intensity $\vec{E}$ and volumetric density of charges ρ depending on the selection of the boundary conditions. /59

Analysis of the obtained solutions results in a conclusion

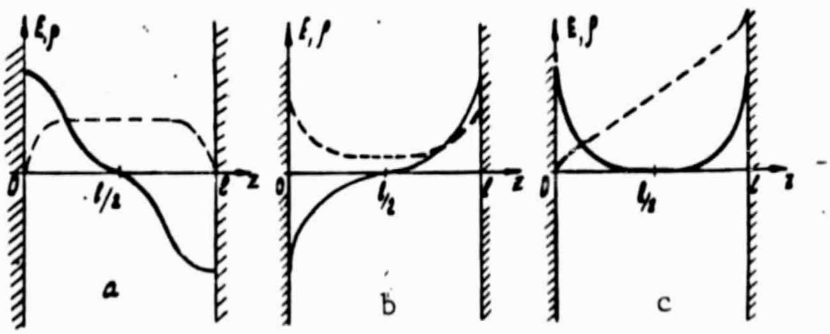


Figure 1. Stationary Distributions of Electrical Field Intensity (dotted line) and Density of Volumetric Charge (solid line) for a) Homopolar, b) Heteropolar and c) Mixed Charge Distributions

regarding possible formation of stationary homo- and hetero-charges, as well as their combinations (fig. 1) in the inter-electrode interval.

The isothermic electroconvective instability of a flat layer of slightly conducting liquid is examined.

2.21. Numerical Study of Thermomagnetic Convection on a Horizontal Cylinder

E. Ya. Blum and A. Yu. Chukhrov (Riga)

Studies of thermomagnetic convection [1, 2] indicated that the presence of a nonuniform magnetic field has a significant influence on heat exchange in liquid magnetic substances. In the absence of a gravitational force in these media, it is possible to maintain intensive convective motion, creating sufficient magnetic field gradient.

When studying convection near a horizontal cylinder in a uniform magnetic field [3], it was shown that twisting of the force /60 lines near the surface results in a change in the structure of the thermal boundary layer. However a correspondence was not achieved between the results of the experiment and the theoretical computations made in the frameworks of the boundary layer theory. Calculation of the magnetoviscous effect also did not yield a satisfactory explanation of this fact.

This work has made a numerical analysis of the thermomagnetic convection near the horizontal cylinder. The problem of planar flow of a viscous magnetized liquid around a horizontal cylinder was solved in the presence of a uniform external magnetic field. The effect of dissipative processes on energy transfer was considered to be negligible and the distortion of the field because of liquid motion was not taken into consideration. The system of equations was written in variables of the current function ψ--vorticity, ω--temperature T.

With numerical study of the free convection near bodies of different shape, we must compute the flow in an unlimited region. In order to use finite - differential methods, it is customary

to introduce an external limiting surface, however the question of the effect of the second boundary on the solution has not yet been completely studied. It should be noted that the temperature in the flux which is lifted above the heated body diminishes with distance sufficiently slowly, therefore, the condition of constant temperature on the external boundary is true only for a large relative distance. In the method suggested in [4], relatively short distance of the external boundary is required, however, it is necessary to assign the direction of the ascending flux which is not always possible in weightlessness in studying convection.

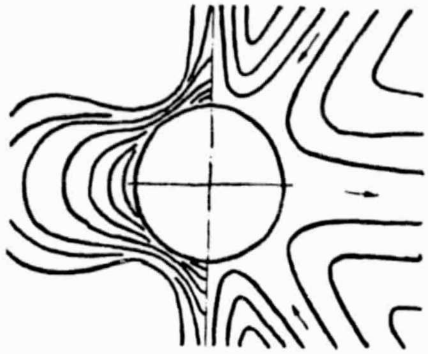
This publication suggests a method for studying flow near a body in which the area of determining variables becomes finite replacement of the argument. For a horizontal cylinder, the new argument looks like $\zeta = \varepsilon^{-n}$ where n--constant. With n > 0, the region $\varepsilon_u \le \varepsilon < \infty$ is depicted in a circle $\zeta_u \geq \zeta > 0$ The function $\tilde{\psi} = \zeta^{1/n}\psi$ is introduced. The boundary conditions for the problem raised above look like: on the cylinder wall with $= \zeta_u$: $T = T_u$, $\tilde{\psi} = \partial\tilde{\psi}/\partial\zeta = 0$; with $\zeta = 0: T = T_\infty, \tilde{\psi} = 0, \omega$
The functions ω and $\tilde{\psi}$ are linked by the equation

$$\frac{\partial^2\tilde{\psi}}{\partial\zeta^2} + \frac{1}{\zeta}\,\frac{n-2}{n}\,\frac{\partial\tilde{\psi}}{\partial\zeta} + \frac{1}{\zeta^2}\,\frac{1}{n^2}\left(\tilde{\psi} + \frac{\partial^2\tilde{\psi}}{\partial\varphi^2}\right) = -\frac{\omega}{n^2\,\zeta^{2+1/n}}\,.$$

When this replacement is used, there is no need for a nonuniform differential grid, since using selection of the parameter n one can guarantee the necessary concentraion of assemblies around the body. /61

Calculations of flow during gravitational convection near a heated cylinder indicated the good correspondence of the heat exchange characteristics and the flow pattern with the experimental data and the results of publication [4]. An evaluation was made of the effect of the external bourda.y on the flow.

Study of the thermomagnetic convection examined the cases of flow of magnetic liquid and paramagnetic electrolyte both near the magnetic and the nonmagnetic cylinders. Dependences were



obtained for the heat exchange characateristics on the magnetic Rayleigh number Ra_m with different ratios of magnetic permeabilities of the medium and cylinder. The characteristic appearance of the flow and isotherm (left) is shown in the figure which corresponds to calculation with $Ra_m = 10^4$, $Pr = 10$, $K\mu = 1$ (see [2]). The average Nusselt number is $\overline{Nu} = 5.2$.

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S2.22. Effect of Rotating Field on Temperature and Uniformity of a Suspension /62

Ye. Ye. Bibik and V. M. Shumilov (Leningrad)

When there is no gravity, regulation of the temperature in an assigned volume is a definite problem. It is consequently important to study the behavior of ferrosuspensions in a rotating field.

It is common knowledge that in a constant field the particles of magnetic material are united into chains. In a rotating field, these chains rotate with field frequency ω, creating a specific torque [1] $M = (p\eta\omega + 2m^2/vr^3)\varphi$ where p, m, v--factor of shape, magnetic moment and volume of the particle respectively, η--viscosity of the medium, r--distance between the particle centers in the chain and ϕ--their volumetric percentage in the suspension.

With an increase in ω, the length of the chains drops and with a certain critical frequency $\omega_1 = 2m^2(\pi\eta a r^5)^{-1}$ or corresponding twisting moment M_1, the chains are broken into individual particles and then $M = M_1\omega/\omega_1$.

Rotation energy of the chains is competely scattered, which results in a rise in temperature T of the suspension at a rate of $M\omega/c_v$ where c_v--heat capacitance of suspension.

Another critical frequency is the frequency of separation of interruption in regular rotation of the individual particles. For particles with rigid magnetic moment $\omega_2 = mH(pv\eta)^{-1}$ and $\omega_2/\omega_1 \gtrsim 9H/\pi p M_s$, where M_s--magnetization of saturation of the magnetic material. In moderate fields, these frequencies are of one order and are roughly equal to $10^5/\eta$ with $M_s = 470$ gauss.

With $C_v \approx 4.2 \times 10^7$ erg/deg x cm^3, this can guarantee rate of temperature rise to 10^4 ϕ/η degrees per second. In the absence of heat removal at any frequencies, the temperature cannot exceed the Curie temperature and should be maintained on this level, since particle rotation ceases when it is reached.

A medium that is nonuniform in viscosity is characterized by spectrum of local critical frequencies $\omega_\wedge$. Depending on the ratio between ω and $\omega_\wedge$, the initial heterogeneity of the suspension (for viscosity, composition, temperature) will diminish or increase under the influence of the rotating field pulse. /63

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S2. 23. Features of Condition of Ferrosuspensions in Variable Field

Ye. Ye. Bibik (Leningrad)

According to [1], the rotating magnetic field (B-field) causes rotation of the entire suspension of magnetic particles as a solid body, and shear flow develops only on the boundary with the vessel walls. In contrast to the B-field, in the variable field, remagnetization of rigid - dipole particles, including those connected into chains,can occur because of their rotation in any direction, for example, rotation of neighboring particles in the opposite directions. It is significant that with high concentrations of particles, friction and dipole interaction between the nearest neighbors do not prevent this rotation. They are capable of rotating in coordination as a system of linked rods forming a square lattice. Shear flow in the narrowest gaps between the particles is missing, which creates minimum friction on the medium. The vortexes of neighboring particles in this case are not compensated for, but are intensified. Their superposition can create directed flow of the medium in any direction at a 45° angle to the direction of the field with cubic packing of the particles.

The rigid bond between the rotation directions of neighboring particles in a concentrated suspension prescribes the formation of flat macroscopic layers with coherent rotation of the particles. On the other hand, the randomness of the initial phase of particle orientation and other factors mean that when the field is inluded, only locally coherent areas of rotation develop. Their competition will cause a rise in some and decrease in the-dimension of other regions and establishment of a certain equilibrium

size and orientation of the coherent rotation regions. The initial conditions, the presence of admixtures, external force pulse, etc. can alter the suspension condition, provoke the formation of different dissipative structures [2], which include diverse states of ferrosuspensions and magnetic liquids in rotating and variable magnetic fields. /64

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S2.24. Features of Numerical Solution to Stefan Problem with Convection in Variables of the Current Function and Velocity Vortex

B. I. Myznikova and Ye. L. Tarunin (Perm')

Numerical study of convection in a melt during hardening is of considerable importance in relation to developing scientific fundamentals for space technology.

Difficulties in solving the Stefan problem with convection are known. Many researchers (V. I. Polezhayev, G. M. Sevost'yanov, K. B. Dzhakupov and others) therefore use different simplifications. Convective flow in a melt zone is most often studied with an assigned law for advance of the phase transition boundary; the simple shape of the liquid region is also assigned in this case. Certain important convection characteristics are successfully clarified in this statement.

A study was made in [1] of the melt motion during hardening, searching for the position of the interface boundary. Figure 2 presents typical patterns of flow at different moments in time (zone of hardened metal is hatched). As is apparent, the shape of the liquid region is close to rectangular for a long time;

a deviation is noted only near the corners. At the initial stage of the process, the velocity and temperature gradients are concentrated near the hardening front. The calculation was made on a fixed grid. The temperature field in the entire calculation region was determined from a solution to the heat conductivity equation on the through light plan suggested by A. A. Samarskiy and /65

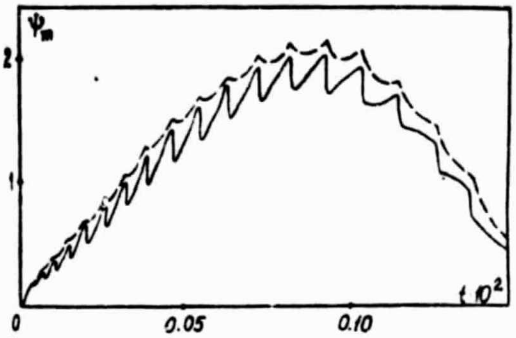

Figure 1.

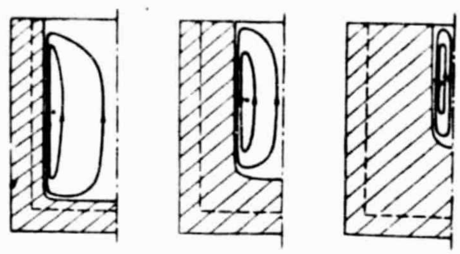

Figure 2.

B. D. Moiseyenko. Considerable difficulties developed in solving the hydrodynamic part of the problem. Analysis and generalization of the procedure for computing the velocity vortex on the solid boundary [2] made in [3] allowed certain computational difficulties to be overcome. Figure 1 illustrates the dependence of the maximum value of the current function ψ_m on time. Pulsations in ψ_m at the moment the interface boundary passes through the grid central points are clearly visible. The pulsation amplitude diminishes when lower relaxation is used under boundary conditions for the vortex (dotted line). The estimates made in solving the model problems indicate that the transition of the crystallization front through the grid central points is inevitably accompanied

by a jump with relative change $\delta\psi \sim 150h$ (h--grid spacing).

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S2.25. Analysis of Heat and Mass Transfer in a Germanium Melt When Monocrystals Are Grown by the Chokhral'skiy Method

I. V. Starshinova, V. A. Smirnov, I. V. Fryazinov (Moscow)

Numerical modeling was carried out of velocity, temperature and concentration fields in a germanium melt when monocrystals were grown 43 mm in diameter with loading of the metal into a 3.4 kg crucible.

Modeling used a differential plan developed in the Institute of Applied Mathematics of the USSR Academy of Sciences which makes analogs of the preservation laws in the initial differential equations, and also reflects the additional relationships expressing a balance of individual types of energy.

The Navier - Stokes and Fourier - Kirchhoff system of equations which describes processes in the melt when monocrystals are grown by the Chokhral'skiy method was solved by the method of longitudinal - transverse trial run. In order to solve the current function equation a Jordan set of parameters is selected and it is iterated to the assigned degree of accuracy. The non-linear terms in the equations are approximated so that they do not contribute to energy and momentum. The terms with viscosity were made monotonic of the second order. The coefficient ε is

introduced with mathematical viscosity. It reduces this viscosity to zero. The Tom formula was used to approximate the vortex at the boundary central points.

The rate of crystal rotation is 30 rpm (Re_k = 10000), crucible 5 rpm ($Re_t \approx$ 10,000), intensity of natural convection Gr = 5 x 10^7. Temperature distribution on the crucible wall near the free melt surface, as well as in the subcrystalline region of the melt was recorded experimentally by VR 5/20 thermocouples and used as the boundary conditions in modeling. /69

Isolines of the current functions, temperatures and concentrations of the alloying admixture in the melt under the influence of only natural convection, natural and forced convection determined by temperature distribution, rotation of the crucible and crystal are presented. The contribution of thermocapillary convection is studied.

S2.26. Thermal Diffusion in Gases as the Reason for Development of Thermoconcentration Convection

A. F. Bogatyrev (Alma-Ata)

A nonuniform temperature field develops in a uniform gas mixture that is in weightlessness because of the presence of different heat sources. The temperature field is the reason for development of thermal diffusion fluxes which in a closed system lead to the appearance of hydrodynamic fluxes in the gas mixture and thermal diffusion separation in the gas mixture. The phenomenon of development of hydrodynamic flux under nonisothermic conditions in pure gases and gas mixtures which has been called thermal diffusion baroeffect has been studied in detail by us in a number of publications.

Calculation of the fluxes developing in pure gas and a gas mixture under nonisothermic conditions can be made in the case of local Maxwell molecular distribution by velocities in the framework of the elementary kinetic theory, by using the

following expression:

$$\vec{\Gamma}_i = c_i \vec{W} - D_i \nabla c_i + \left(\frac{1}{2} - A_i\right) c_i D_i \nabla \ln T, \tag{1}$$

where $\vec{\Gamma}_i$ --density of volumetric flux, $D_i = \frac{1}{3} l_i v_i$ --partial coefficient of diffusion, c_i--volumetric concentration, $\vec{W}$--velocity of hydrodynamic gas flux as a whole, A_i--constant computed on the basis of the potential of intermolecular interaction. The partial diffusion coefficient D_i in the case of pure gas coincides with the self-diffusion coefficient, and for the mixture can be found /68 from formulas of the elementary kinetic theory or computed through the coefficient of mutual diffusion in the case of a binary mixture of gases.

If we are dealing with a gas mixture, then all the fluxes of the components under the influence of the temperature gradient will be directed to one side; different velocities are determined by the magnitude of the D_i and A_i coefficients. As a result of this, a concentration shift ΔC develops in the mixture of uniform composition. Its magnitude for a closed system can be computed in a binary mixture of gases according to the following formula of the elementary kinetic theory:

$$\Delta C_1 = C_1 C_2 \frac{\left(\frac{1}{2} - A_1\right)\sqrt{m_2} - \left(\frac{1}{2} - A_2\right)\sqrt{m_1}}{\sqrt{m_1}\, c_1 + \sqrt{m_2}\, c_2} \ln \frac{T_2}{T_1}, \tag{2}$$

where m_1 and m_2--masses of the molecules, T_2 and T_1--temperature of hot and cold vessels respectively.

The magnitude of separation in the multiple-component system can be easily computed through separation in binary mixtures as follows:

$$\Delta C^{M} = C_i^2 \sum_{j=1}^{2} \frac{\Delta C_{ij}}{C_{ij}^2} \tag{3}$$

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where ΔC_{ij}--magnitude of thermal diffusion separation in a binary mixture, and C_{ij} and C_{ji}--volumetric concentrations of components i and j in a binary mixture on the condition that $(C_i/C_j)_{MH} = (C_i/C_j)_{bin}$. In the closed system, the developed thermal diffusion flux should be compensated for by a reverse hydrodynamic gas flux as a whole, that is, hydrodynamic fluxes directed from the hot region of gas to the cold will constantly exist in this system. In the case of strictly selected conditions, thermal diffusion separation will exist in the system whose magnitude can be computed from the following ratio for the binary mixture:

$$\Delta C^{\circ} = \frac{\Delta C_1^{p}}{1 + \left(1 - \frac{a}{2}\right) \frac{C_1\sqrt{m_2} + C_2\sqrt{m_1}}{C_1\sqrt{m_1} + C_2\sqrt{m_2}}} \ln \frac{T_2}{T_1}, \qquad (4)$$

/69

where ΔC_1^{p}--separation in a closed system, a--constant associated with A_i.

The developed separation in turn results in diffusion fluxes and diffusion baroeffect, that is, the appearance of convective mass fluxes in the system.

Thus, the phenomenon of thermal diffusion in the gases in weightlessness is one of the reasons for the development of convection. By using the ratios (1) - (4), one can compute the magnitude of hydrodynamic flux that develops in gases in non-isothermic conditions as a result of thermal diffusion.

S2. 27. Experimental STudy of Thermal Concentration Convection with Small Rayleigh Numbers

A. Yu. Pinyagin, A. F. Pshenichnikov, G. F. Shaydurov (Perm')

Use of gas mixtures in studying thermal concentration convection makes it possible to vary the concentration and thermal numbers of Rayleigh in broad limits. This permits modeling of certain processes of heat and mass exchange occurring in

two - component solutions and melts in reduced gravitation.

This work studied temperature and concentration fields in a rectangular cavity heated from the side. The lower and upper cavity boundaries were made of sheet brass. The side boundaries were made in the form of a multilayer copper grid permitting maintenance of the necessary distribution of temperature. The grids were blown through from the outside by different gases which permitted a condition of third order for concentration to be created on the side boundaries. The model from the ends was restricted by thin plane - parallel glass. /70
Temperature measurements were made using copper -constantan thermocouples. The model was placed in the working space of a holographic interferometer of real time to study the concentration fields.

The studies indicated the complex nature of the mutual influence of the concentration and temperature fields. A dependence of the magnitude characterizing the distortion of the concentration field on the concentration and thermal numbers of Rayleigh was obtained.

S2.28. Numerical Study of Mixing of Two Gas Media with Supply of One Gas and Removal of the Mixture from a Cylindrical Volume

G. A. Dolgikh, A. I. Feonychev, and A. M. Frolov (Moscow)

Obtaining of epitaxial layers by the method of gas transport transfer, ventilation and air conditioning, and production of chemical compounds from gas mixtures, these and many other technological processes require a study of flow and heat and mass exchange during mixing of gas media. There are few publications in this area. Publication [1] uses the method of successive approximations to solve the one - dimensional problem of admixture distribution during laminar flow of gas mixtures in a circular tube. Publication [2] made a numerical study of the forced and thermal convection in a flat region, assigning the Poiseuille profile at the inlet, and gas consumption at the outlet.

This work used the equations of heat and mass exchange and gas motion in the Boussinesq approximation to study forced, thermal and concentration convection in a cylindrical asixymmetrical volume of radius R and height H when gas is supplied with concentration C_o and temperature T_o on one of the ends through an opening of radius R_1 or through an annular slit with external and internal radii R_2 and R_3. The mixture moves through the tube of radius R_4 on the other end. A velocity profile, uniform or Poiseuille, was assigned at the inlet to the studied volume, and the Poiseuille profile at the outlet from the outlet pipe. Some calculations assumed that the length of the outlet pipe H_{tp} equalled zero. /71

Figure 1 for the moment of time $\tau = ut/R = 0{,}712$ presents current lines ψ, distribution of the dimensionless concentration of admixture $C = (C - C_o)/(C_1 - C_o)$ for coordinate z on the wall (r = 1.0) and on the axis (r = 0.0) on the condition of uniform supply of gas over the entire section of the end z = 0 at a rate of u and removal of the gas mixture through the opening of radius $R_4 = 0.3R$ on the end z = H/R = 3.0 with assigned profile of Poiseuille velocity at the outlet. The Reynolds number equals 10, the Grashof number for thermal and concentration convection equals 10^3, the Schmidt and Prandtl numbers equal 1.0. The closed vortex near the side wall is governed by the effect of thermal convection. An admixture concentration gradient occurs on the radius with increased content of gas of the initial composition near the side wall. The position of the "gas piston" front (without diffusion of the gas components and with uniform velocity profile over the volume section) is indicated by the dot-dash line. The front of supplied gas is considerably in advance of the "gas piston" front because of acceleration of the flow near the axis and diffusion.

Figure 2 presents the change in time in the admixture concentration which is average over the volume. Curve 3 was obtained with Reynolds number equal to 50, and Schmidt number

equal to 10 and H/R = 3.0; curve 4 with Reynolds number 100, Schmidt number 1.0 and H/R = 3.0. Straight lines 1 and 2 corres-

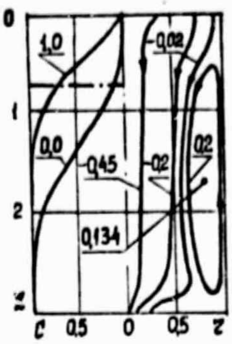

Figure 1.

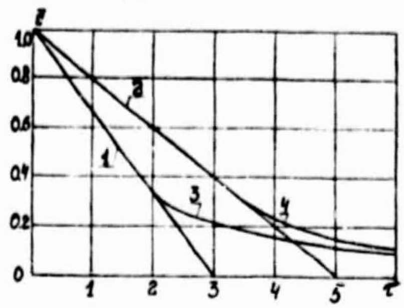

Figure 2.

pond to the case of flow in a "gas piston" mode for H/R equal to 3.0 and 5.0 respectively. These straight lines intersect the axis of time at moment τ_0 = H/R, which corresponds to the moment of complete [illegible] of gas of initial composition in the "gas piston" mode. Before moment in time $\tau \cong 0.7\tau_0$, the average gas concentration with calculation of the convective and diffusion /72 mixing changes in time by the linear law, as in the "gas piston" mode. Then, when the introduced gas reaches the outlet opening, the admixture concentration which is average over the volume begins to deviate from the ideal "gas piston" mode.

The calculations show that the length of the outlet pipe only influences the distribution of velocity and admixture concentration near the outlet opening and has a comparatively small effect on the flow structure and the average concentration of admixture in the volume.

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S2. 29. Diffusion Coefficients and Equations of Hydrodynamics of Nonequilibrium Gas Mixture in Different Reference Systems

N. D. Kosov (Alma-Ata)

We will generalize the concept of flow velocity of a non-equilibrium mixture for a random system of reference, after defining it from the transfer of physical property ψ (number of particles, mass, pulse, quantity of substance, volume, etc.) as follows:

$$\vec{v}_0^{\psi} = \left(\sum n_i \psi_i \bar{\vec{v}}_i\right) / \sum n_i \psi_i, \tag{1}$$

where $\bar{\vec{v}}_i$ --average velocity in relation to the "fixed" system of reference, n_i--numerical density of the molecules; lower index indicates the affiliation to the i-th mixture component.

The density of the diffusion flux in relation to the platform moving with flux velocity (1) will equal

$$\vec{j}_i^{\psi} = c_i^{\psi}\left(\bar{\vec{v}}_i - \vec{v}_0^{\psi}\right) = \psi_i \vec{j}_{in}^{\psi} = -\mathcal{D}_i^{\psi} \nabla n_i, \tag{2}$$

where $\vec{j}_{in}^{\psi}$, $\mathcal{D}_i^{\psi}$ --density of the diffusion flux of molecules and diffusion coefficient respectively in the reference system ψ, /73
$c_i^{\psi} = \psi_i n_i$ --density of the physical property ψ.

The condition of fixing the reference system is placed on fluxes (2)

$$\sum \vec{j}_i^{\psi} = 0. \tag{3}$$

For the observer moving at flux velocity (1), i.e., fixing the reference system for (3), the following condition will be fulfilled

$$\sum n_i \psi_i \bar{\vec{v}}_i = \sum n_i \bar{\vec{V}}_i^{\psi} \psi_i = -\sum \mathcal{D}_i^{\psi} \psi_i \nabla n_i = 0, \tag{4}$$

since in this case the average velocity of the component in relation to the moving observer will equal the diffusion velocity

$$\overline{\overline{V}}_i = \overline{\overline{v}}_i - \overline{v}_0^{\psi}. \tag{5}$$

For the "fixed" observer usually connected to an instrument (laboratory reference system), the mixture flux velocity (1) is generally equal to zero.

For a binary mixture, the ratio between the diffusion coefficients for the average numerical counting system ($\psi_i = 1$) and the system of the center of mass ($\psi_i = m_i$) will look like:

$$\mathcal{D}_1^n = \mathcal{D}_2^n = \mathcal{D}_{12}, \quad \mathcal{D}_1^m/\mathcal{D}_2^m = m_2/m_1, \tag{6}$$

where D_{12}--coefficient of mutual diffusion, m--molecular mass.

With $\psi_i = m_i c_i$, where $c_i = \sqrt{8kT/\pi m_i}$ --average velocity of thermal motion of molecules, we obtain the average pulse system of counting, for which

$$\overline{v}_0 = \left(\sum n_i \sqrt{m_i}\, \overline{\overline{v}}_i\right) / \sum n_i \sqrt{m_i}, \quad \mathcal{D}_1/\mathcal{D}_2 = \sqrt{m_2/m_1}. \tag{7}$$

The link between the diffusion coefficients in different counting systems looks like:

$$\mathcal{D}_1 = \frac{\sqrt{m_2}\, \mathcal{D}_{12}}{c_1\sqrt{m_1} + c_2\sqrt{m_2}}, \qquad \mathcal{D}_1^m = \frac{m_2 \mathcal{D}_{12}}{c_1 m_1 + c_2 m_2}. \tag{8}$$

$$\mathcal{D}_{12} = \frac{c_1\sqrt{m_1} + c_2\sqrt{m_2}}{\sqrt{m_2}} \mathcal{D}_1 = \frac{c_1 m_1 + c_2 m_2}{m_2} \mathcal{D}_1^m. \tag{9}$$

The coefficients D_2 and D_2^m are obtained by replacing the index 1 by the index 2 in formula (8).

From the general Enscog transfer equation, equations of hydrodynamics were obtained for a random reference system which differ from the normal equations in the system of the center of mass because there are terms that take into consideration the diffusion transfer of mass, pulse and energy. The continuity equation looks like:

$$\frac{\partial \rho}{\partial t} + \frac{\partial}{\partial z}\left(\rho \vec{v}_0^{\psi} + \sum n_i m_i \overline{\overline{V}}_i^{\psi}\right) = 0. \tag{10}$$

The following terms appear in the motion equation

$$\frac{\partial}{\partial t} \sum n_i m_i \overline{\overline{V}}_i^{\psi} + \vec{v}_0^{\psi} \frac{\partial}{\partial z} \sum n_i m_i \overline{\overline{V}}_i^{\psi}, \tag{11}$$

and in the energy equation

$$-\left(\frac{d\vec{v}_0^{\psi}}{dt} \sum n_i m_i \overline{\overline{V}}_i^{\psi}\right) + \left(u^{\psi} \frac{\partial}{\partial z} \sum n_i m_i \overline{\overline{V}}_i^{\psi}\right). \tag{12}$$

The last term in (10) and both terms in (11) and (12) equal zero only in the system of mass center.

A correct solution to the problem is possible only on the condition that all the necessary equations are taken in the same system of counting, otherwise the problem of total mass transfer in a nonuniform gas mixture will not be correctly solved.

S2.30. Dissemination of Light Rays in a Binary Mixture in Weak Thermoconcentration Convection /75

I. G. Avgustinovich, L. P. Vozovoy, V. I. Yakhushin (Moscow, Perm')

An improvement in the optical parameters of items of design optics is an important technical problem. Its solution requires

having a concept about the nature of the developing optical distortions and numerical evaluation of their magnitude. Because of the unequal temperature in the walls of the optical device elements, a nonuniform distribution of the refraction index is established in the medium that fills these devices. This results in deviation of light rays from rectilinear dissemination. Calculation of these deviations may prove necessary in fulfilling certain precision optical measurements.

If the medium is a multiple-component (for example, binary) mixture, its density and refraction index will depend not only on the temperature, but also on the concentration of mixture components. In the case where molecules of the heavy component will be arranged in the region with higher temperature in a sufficient quantity, one can assume that heterogeneities in the density and refraction index will be considerably diminished.

It is common knowledge that in a heterogeneous mobile medium that is in the field of mass forces, convection develops. Distributions of temperature, concentration and the refraction index will be determined by the shape and intensity of the convective motion. Thus, the light ray trajectories can be computed only on the basis of preliminary solution to the convective problem.

This work studies the effect of weak convection on the dissemination of light rays in a flat plane of rectangular shape filled with transparent two - component gas mixture. The system of equations of thermoconcentration convection which is written in the Boussinesq approximation with regard for thermal diffusion and diffusion heat conductivity was solved by the finite - differential method by the plan of longitudinal - transverse trial run. Using the refraction index distribution found (it depends not only on the temperature and concentration, but also on the optical properties /76
of the mixture components characterized by the refraction coefficient), the angular deviations of the rays falling perpendicularly to the side wall of the cavity were computed.

The calculations were made for Rayleigh numbers $R \lesssim 10^5$ which for certain types of optical units correspond to the value of specific force about 10^{-2} N. An examination was made of several cases of boundary conditions for concentration: a) cavity is impermeable for the substance; b) boundaries parallel to the direction of ray spread have the same or different concentration constants.

Computations were made for different thermophysical and optical parameters of the mixture which determine the Rayleigh number R, Prandtl P, Schmidt S, coefficients of thermal diffusion, diffusion heat conductivity and refraction. A systematic study was made of the effect of these factors on the magnitude of angular deviations in the rays. The optimal values were found for the parameters which guarantee the least optical distortions.

It was established that the angular deviations increase with a rise in convection intensity. With fixed R, thermal diffusion parameter ε_t has a significant effect on the propagation of the rays, and the angular deviations can both be increased, and decreased with a rise in ε_t depending on the optical properties of the mixture. The effect of other mixture parameters (P, S, diffusion heat conductivity) is comparatively low. If different concentrations are maintained on the horizontal boundaries, then the angular deviations can be diminished even in the absence of thermal diffusion.

Maps of current lines, isotherms and isolines of equal concentration were constructed.

S2.31. Features of Convective Motion in Large Centrifugal Fields

G. V. Yastrebov (Perm')

Thermal convection under weightlessness can be excited by centrifugal forces. In order to model centrifugal convection under /77 terrestrial conditions it is necessary to create strong centrifugal fields, then the gravitational force can be ignored as compared to the centrifugal.

This work made an experimental study of thermal convection in a thin, rapidly rotating cylindrical layer of liquid when there is a radial temperature gradient. The experiments were conducted with water filling the cylindrical gap of the rotor, whose rotation rate could change in stages from 1200 to 5000 rpm, which corresponds to the centripetal accelerations from 45g to 800 g, where g--free fall acceleration.

Using the electrochemical technique of visualization, a study was made of the structure of convective motion which is shafts oriented along the rotation axis. A differential rotation was found in the system of convective shafts. Possible reasons for this effect are studied.

Measurements were made of the longitudinal components in the velocity of convective motion in shafts depending on the Rayleigh number. With small supercriticalities, the magnitude of velocity rises proportionally to the square root of the supercriticality.

S2.32. Study of Thermal Convection in a Cylinder Rotating around Its Axis

V. M. Kapinos, V. N. Pustovalov, A. P. Rud'ko, Yu. Ya. Matveyev
(Khar'kov)

An experimental study was made of thermal convection which develops in the field of inertia forces in a cylindrical cavity rotating around its axis. The limiting disks are maintained at constant temperatures. The temperature along the generatrix changed according to linear law.

Acceleration of the gravitational force under experimental conditions on the average was 50 times lower than the centrifugal acceleration, therefore its influence was not taken into consideration.

The model section of the experimental unit was formed by glass - textolite and duralumin disks, connected in the peripheral

part by a glass-textolite ring. The cavity radius was 0.3 m, and the distance between the disks 0.14 m. The glass-textolite disk which models the heated side surface of the rotor is equipped with fourteen concentric band heaters made of thin foil. The inner surface of the ring had four heaters. /78

Methods of mathematical statistics were used to generalize the study results.

The experiments indicated that the average heat emission of the heated disk essentially does not depend on the rotation frequency of the system and the temperature pressure, and is roughly 11 - fold greater than the heat flux computed for pure heat conductivity. This is explained by the fact that the development of thermal convection is slowed down by the effect of the Coriolis inertia forces that reduce the velocity of the liquid in relation to the cavity boundaries.

The existence of two regions with different laws for the change in thermal flux density over the radius was found on the hot side of the cavity. The separating radius which determines the presence of a peripheral region slightly depends on the mode parameters in the studied range of their change and is approximately equal to 0.6 of the cavity radius. Within each of the regions, the average heat emission essentially does not depend on the Grashof number, which is an indication that both oppositely acting factors, intensification of heat output of free convection with a rise in temperature pressure and rotation frequency, on the one hand, and the effect of the Coriolis force, on the other hand, mutually compensate for each other.

The report presents similarity equations which describe the local heat emission of the more heated disk and peripheral boundary of the cavity, as well as the average heat emission of the less heated disk.

Numerical analysis of thermal convection in the examined system was based on the Navier - Stokes and energy equations in the Boussinesq approximation. The solution used an explicit monotonic conservative finite - differential plan [1], which made a number of changes in order to improve the accuracy and increase the rate of convergence of the iteration process. In the area of small Gr numbers, stationary distributions were obtained for the current lines, isotherms and Nusselt numbers.

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S2.33. Numerical Study of Centrifugal Convection in a Cylindrical Layer

V. I. Chernatynskiy (Perm')

An examination is made of convection of liquid which is between two coaxial isothermic cylinders rotating with constant angular velocity with more heated external cylinder. The convection equations in the Boussinesq approximation are written in the rotating system of coordinates on the assumption that the centrifugal acceleration is great as compared to the acceleration of the gravitational force, so that the mass force is directed on the radius from the rotation axis. Under these conditions, mechanical equilibrium (solid rotation) of the liquid is possible. In the case of a thin layer, with a rise in the temperature differential, it becomes unstable in relation to perturbations in the form of swells (rolls) oriented along the rotation axis [1]. This work uses the Galerkin method to find the neutral curves for these perturbations with different thicknesses of the layer. The dependence of minimum Rayleigh number defined through the thickness of the layer, and the number of swells in the layer on its thickness are defined. The grid method was used to study the supracritical flow modes. The finite - differential plan was constructed with

regard for the nonuniform compendency of the integration region. Calculations were made on a 10 x 20 grid for different Rayleigh number values and layer thickness with fixed value of the Prandtl number P = 1. With small supracriticalities, the flow structure corresponds to the structure of the most dangerous perturbation. With a further rise in the Rayleigh number, self - oscillating flow modes develop in which the rolls oscillate in a radial direction.

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S2.34. Thermal Convection in a Force Field of Variable Intensity /80

A. K. Sinitsyn and V. Ye. Fertman (Minsk)

Mathematical modeling of transfer processes under conditions close to weightlessness has become an urgent problem because of the development of space equipment and technology. The weak force fields that are active under these conditions are characterized by spatial heterogeneity of intensity (acceleration). For example, during rotation of the space apparatus $a_u \sim$ [illegible] , and in the gravitational field of the apparatus $a_c \sim 1/$[illegible].

This report presents results of numerical modeling of thermal convection in a square section cavity with "heating from the side" and the presence of heterogeneous acceleration of the mass force over the height. Equations are examined in the Boussinesq approximation. The temperature on the vertical boundaries is maintained constant, and on the horizontal, it changes according to the linear law.

An examination was made of two laws for the change in acceleration over the height: a) acceleration rises linearly with height $a_u = a^*(y_0+y)/y_0$ (rotation of apparatus); b) it diminishes inversely proportionally to the height (self - gravitation) $a_c = a^* y_0/(y_0+y)$; here y--dimensionless coordinate on the

vertical ($0 \leq y \leq 1$); a^*--acceleration on the lower edge of the square; y_0--parameter which characterizes the magnitude of heterogeneity of acceleration over height and determined by the distance of the examined cavity from the rotation center a) or center of mass b) of apparatus. With $y_0 \to \infty$, we obtain $a_u = a_c = a^*$.

Numerical calculations were made according to the technique presented in publication [1] for the Prandtl number Pr = 1.

In contrast to the results of numerical modeling of thermal convection in cylindrical geometry [2], the effect of the type of heterogeneity of acceleration over height on the structure of convective motion was found. In the case a), the convective cell is pressed to the upper boundary of the cavity, near which the local circulation velocity of the liquid rises; in case b), a similar effect is observed near the lower edge.

Analysis of the effect of acceleration heterogeneity on heat exchange indicates that a strong dependence of dimensionless heat flux on the quantity y_0 is observed for y_0 smaller than 1, which corresponds to the more than double drop over the height of the cavity in the Grashof number. This result agrees with the result of publication [3]. /81

Heterogeneities in field intensity for which $y_0 > 5$ do not have practical effect on heat exchange (see figure) in the studied range of change in the Gr number. In this case one may not take into consideration the acceleration heterogeneity over the fluid volume.

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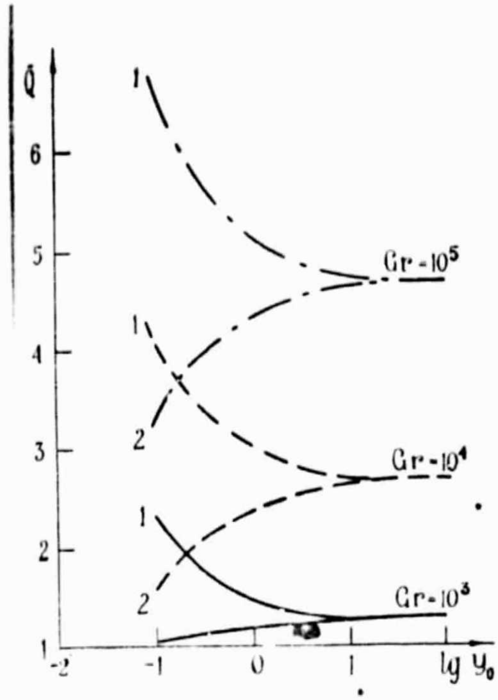

Figure. Dependence of Average Dimensionless Heat Flux through Cavity on Parameter y_o:

$$1 - a_{ц} = a^* \frac{y_0 + y}{y_0}, \quad 2 - a_c = a^* \frac{y_0}{y + y_0}.$$

S2.35. Convective Diffusion in Rotating Spherical Layer /82

A. P. Grigin, B. I. Il'in, N. V. Pet'kin (Moscow)

An examination is made of convective diffusion in a spherical layer formed by a sphere of radius R_1 placed in a sphere of radius R_2. The space between the two spheres is filled with electrolyte. The external surface of one sphere and the internal surface of the other are respectively the cathode and anode of the oxidation and reduction reaction. Both spheres rotate with angular velocity ω which governs the appearance of a centrifugal force field acting on the solution. It is hypothesized that the rate of the chemical reaction on the electrodes is considerably greater than the rate of supply of reacting substances to it. In this case, when the reaction occurs in the system, a concentration gradient appears C(r) for the reacting substances. This results in a density gradient in the solution. Because of heterogeneous density of the liquid, convective motion of the solution appears in the system. It increases the rate of supplying the reacting substances to the electrodes and correspondingly, the maximum current in the circuit.

The equations which describe the stationary convective diffusion in the rotating spherical layer look like:

$$(\vec{v}\nabla)\vec{v} = -\frac{\nabla p}{\rho} + \nu\Delta\vec{v} - \frac{1}{\rho}\frac{\partial\rho}{\partial c}c\vec{\omega}\times(\vec{\omega}\times\vec{r}). \tag{1}$$

$$div\,\vec{v} = 0, \tag{2}$$

$$\vec{v}\nabla c = \mathcal{D}\Delta c. \tag{3}$$

The addend with double vector product in (1) describes the field of centrifugal forces; it is believed that the pseudovector $\vec{\omega}$ passes through the center of the sphere. The boundary conditions of the problem look like:

$$\vec{v}|_{R_1} = 0, \qquad \vec{v}|_{R_2} = 0, \tag{4}$$

$$c|_{R_1} = 0, \qquad c|_{R_2} = c_0. \tag{5}$$

Since $rot\,[c(r)\vec{\omega}\times(\vec{\omega}\times\vec{r})] \neq 0$, then convection occurs with the lowest /83 angular velocity desired ω. In this case, solution to the problem (1) - (5) was found in the form of a series for small parameter $\lambda \sim \omega^2$.

This work in the first approximation for λ finds the hydrodynamic field of solution velocities, as well as the change in diffusion flux caused by convective transfer of ions.

S2.36. Numerical and Analytical Methods for Solving Heat and Mass Transfer Problems with Natural Convection in Low Gravity Conditions

V. S. Kuptsova (Moscow)

One of the features in studying the processes in weak fields of mass forces is that the physically small perturbations in the temperature or dynamic fields have a significant effect on the distribution of unknown parameters. This makes it necessary to have especially thorough calculation of all interacting factors, and in particular, to solve the tasks of heat and mass exchange in the associated statement. The solutions obtained by numerical methods (in particular, method of finite differences), despite the great universality and their truly enormous potentialities, suffer from chronic shortcomings associated with the applied conditions of convergence, stability, conservativeness, etc. It is therefore desirable to obtain solutions which are free of these shortcomings as far as possible.

This work presents solutions to the problems of natural convection for cavities of certain canonical forms with small gravitational forces ($g/g_0 \leq 10^{-2}$). For a complete system of transfer equations in the framework of the Boussinesq approximation, methods were used of integral transforms, and the nonlinear convective terms were represented by source terms which are sought for by iterations. The solution for the vertical slit was made for /84
mathematical formulation of the problem of natural convection in variables T, ψ which includes an energy transfer equation and equation for ψ of the fourth order (which excludes the need for using an equation for the vortex).

The energy transfer equation:

$$\frac{\partial T}{\partial \tau} + u\frac{\partial T}{\partial x} + \beta v \frac{\partial T}{\partial z} = \frac{\partial^2 T}{\partial x^2} + \beta^2 \frac{\partial^2 T}{\partial z^2} ;$$

the pulse transfer equation:

$$\frac{\partial \nabla^2\psi}{\partial \tau} + \frac{\partial \nabla^2\psi}{\partial x} + \beta v \frac{\partial \nabla^2\psi}{\partial z} \quad Pr\, \nabla^2\nabla^2\psi - Gr\, Pr^2 \frac{\partial T}{\partial x} .$$

The solution looks like

$$T = \sum_{n=1}^{\infty}\left\{\left[\sum_{m=0}^{\infty} \frac{\sqrt{2}\sin\frac{2n-1}{2}\pi x\,\sqrt{2}\cos m\pi z}{[0.5(2n-1)\pi]^2+(m\pi b)+1/\Delta\tau_k}\cdot\int_0^1\int_0^1\left(\frac{T_{k-1}}{\Delta\tau_k}+\dot{T}\right)\times\right.\right.$$

$$\left.\left.\times\sqrt{2}\sin\left(\frac{2n-1}{2}\pi x\right)\sqrt{2}\cos m\pi z\,dx\,dz\right]-\frac{2n-1}{2}\pi\right\},$$

$$\psi = -\sum_{m=1}^{\infty}\sum_{k=1}^{\infty}\frac{2}{\mu_{km}^2 N_{km}}\left(\sin\lambda_{2km}x-\frac{\sin\lambda_{2km}}{sh\,\lambda_{1km}}sh\,\lambda_{1km}x\right)\times\sin m\pi z\cdot$$

$$\cdot\int_0^1\int_0^1\dot{\psi}\left(\sin\lambda_{2km}x-\frac{\sin\lambda_{2km}}{sh\,\lambda_{1km}}sh\,\lambda_{1km}x\right)\sin m\pi z\,dx\,dz,$$

where T and ψ--"source terms"

$$\dot{T} = \frac{T_{k-1}}{\Delta\tau_k} - u\frac{\partial T}{\partial x} - bv\frac{\partial T}{\partial z},$$

$$\dot{\psi} = \frac{\nabla^2\psi_{k-1}}{Pr\,\Delta\tau_k} - Gr\,Pr\frac{\partial T}{\partial x} - \frac{u}{Pr}\frac{\partial\nabla^2\psi}{\partial x} - b\frac{v}{Pr}\frac{\partial\nabla^2\psi}{\partial z},$$

$$N_{km} = \frac{1}{2}\left(1-\frac{\sin 2\lambda_{2km}}{2\lambda_{2km}}\right)+\frac{1}{2}\frac{\sin^2\lambda_{2km}}{sh\,\lambda_{1km}}\left(\frac{sh\,2\lambda_{1km}}{2\lambda_{1km}}-1\right),$$

$$\lambda_{1,2km} = \sqrt{\sqrt{\mu_{km}^2+(Pr\,\Delta\tau_k)^2}\pm\left[(m\pi b)^2+(2\,Pr\,\Delta\tau_k)^{-1}\right]}.$$

The findings are compared with the results of the available numerical solutions. Solutions for horizontal and vertical cylinders and spherical cavity are also obtained in the form of quadratures. /85

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S2.37. Numerical and Experimental Study of Conjugate Heat Exchange for Horizontal Cylinder in a Weak Mass Force Field

V. S. Kuptsova, A. V. Korol'kov, A. I. Batarin, and V. G. Malinin (Moscow)

A mathematical model and numerical solution are presented for the problem of nonstationary conjugate heat exchange for a horizontal cylinder filled with liquid and surrounded by a liquid medium, under conditions of a weak mass force field ($g/g_o \leq 10^{-3}$). Mathematical formulation of the problem is given in variables T, ψ, ω in the framework of the Boussinesq approximation. The system of energy, pulse transfer equations, and equation for linking ψ and ω for the internal and external regions is solved numerically by the method of finite differences according to the modified explicit finite differential plan [1]. The conjugate condition used is the equation of balance in the energy effects compiled for the element of thin heat - conducting cylinder shell with regard for heat transfer by heat conductivity in a circular direction [2]. As a result of the solution, features were revealed tor development of the processes of natural convection inside the cylinder and in the external region, temperature fields were constructed, and functions of current and velocities with regard for the mutual effect of the contacting media (liquid - solid shell -liquid). It was indicated that the use of the balance equation as a condition of conjugation instead of the boundary condition of the fourth order results in an improvement in the accuracy of the numerical solution and improvement in the conservativeness of the plan. A criterion is presented for /86
conjugation, from whose magnitude one can establish the need for solving the problem in the conjugate statement. Dimensions of the zone of influence in the external region are defined. The convective heat exchange inside of the cylinder affects it. Change in the radius of influence depending on the physical properties of the medium, intensity of motion and time is defined with accuracy 0.5%. The findings from the numerical solution for distribution of the temperature field inside and outside of the cylinder were compared with the experimental results made by the authors for the Grashof numbers to $Gr = 10^6$. Experiments were made on the shadow instrument of Tepler with photorecording of the temperature gradient fields and recording of the change in the shell temperature in time using

C-2

chromel - alumel thermocouples. The thermocouples arranged in the liquid inside of the cylindrical cavity recorded the significant temperature stratification also obtained in the numerical solution. The data on the temperature fields in the liquid and in the shell that were found in the experiment and in the numerical solution agree well among themselves.

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S2.38. Numerical Methods of Computing Convective Flows in Closed Regions with Reduced Gravitation

N. N. Borodina, A. F. Voyevodin, N. A. Leont'yev (Novosibirsk)

An examination is made of convective flow of a viscous incompressible liquid in a closed region (circle, square with assigned law of temperature change on the solid wall. With Navier - Stokes equations written in variables of the current - vortex function, based on the method of fractional steps, an algorithm is suggested for solving implicit differential equations with accurate realization of the adhesion conditions on the solid wall. /87

In the case of flow in weak gravitation, the flow rates are low and the nonlinear terms can be computed for the lower layer. In this case the restrictions for the grid spacing for the Kurant condition allow selection of a fairly large step in time, and the implicit differential equations have constant coefficients. This fact can be used when solving them using a modification of the trial run parameter with parameter. It is expedient to select as a trial run parameter a combination of solution values on the boundary and its derivative, so that the first trial run coefficient equals the maximum value . Then the other trial run coefficients

are constant and equal this coefficient. The trial run method for the parameter makes it possible to express the solution in the internal points through the parameter values on the boundaries also in solving the differential equations. This presentation allows only boundary conditions to be obtained for a vortex from the condition for current function.

Detailed study of the method, in addition to the implicit technique, uses the method of computing convective flows in the main variables based on the explicit plan of the marker and cell method that uses the approximation of adequate terms by directed differences. The calculations take into consideration the change in viscosity and heat conductivity depending on temperature.

In order to compute velocities, pressure and temperature in the new time layer, initially the pressure gradient field was computed from a solution to the Gilbert problem for a nonuniform system of Cauchy - Riemann equations and auxiliary velocity fields. Then fulfillment of the conditions for mass preservation is monitored, and if necessary, the velocity field is reorganized by iteration. The mass preservation equation is fulfilled in each cell for this purpose. The temperature field is computed after this.

S2.39. Conjugate Problem of Convection in Closed Cavity Surrounded by Heat Conducting Massif /88

V. A. Mazurov, B. I. Myznikova, Ye. L. Tarunin, B. N. Fedorov, Ye. A. Chertkova (Moscow, Perm')

With small values of the Rayleigh number in a closed cavity heated from below, mechanical equilibrium is possible. In many practical situations, the equilibrium conditions are approximately fulfilled and it becomes necessary to compute the finite disorders in these conditions. The increased interest in examining these situations is noted in [1].

This publication studies the case of disrupted equilibrium conditions associated with the effect of conjugation of problem

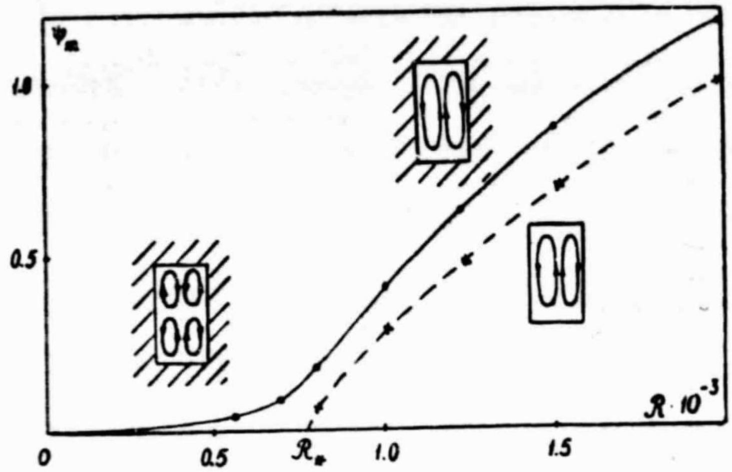

Figure 1.

statement. A numerical study was made of the axial -symmetrical convection in a vertical cylinder with regard for the thermophysical properties of the surrounding massif. The temperature gradient corresponding to heating from below is assigned far from the cavity in the massif.

The dependence of the maximum value of the current function ψ_m on the Rayleigh number R is illustrated in figure 1 (solid line). As is apparent, with $R < R_*$, there is low - intensive flow in the cavity ($R_* \simeq 706$--critical number determining the convection threshold in the task without consideration for the conjugation). In the vicinity of point R_*, the convection intensity increases and a smooth rearrangement of the flow pattern occurs. The dotted line shows the amplitude curve for the problem where the boundary value conditions are directly assigned on the boundary of the liquid region.

It follows from the presented calculations that the real description of the process requires a conjugate statement.

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S2.40. Convective Movements of Nonnewtonian Liquid in Reduced Gravitation

T. P. Lyubimova (Perm')

A study was made of convective motion of a viscoplastic liquid in a closed region heated from the side. An examination was made of the range of Rayleigh numbers corresponding to small values of gravitational force acceleration (g/g_o about 10^{-3}). The Williamson model is used to describe the rheological behavior of the liquid:

$$\tau_{ik} = \left(\mu_\infty + \frac{\tau_0}{\alpha + \sqrt{I_2}}\right) \dot{e}_{ik}, \qquad (1)$$

where τ_{ik}--tensor of viscous stresses, $\dot{e}_{ik}$--tensor of deformation rate, I_2--second tensor invariant $\dot{e}_{ik}$; $\mu_\infty, \tau_0, \alpha$ rheological constants.

The problem is solved by the grid method using a divergent finite differential plan. Rectangular regions extended on the vertical are examined with ratio of the sides ℓ = 1, 2, 5. It is indicated that with small values of the Rayleigh number, intensity of convective movement of the Williamson liquid is low. When a certain value of the Rayleigh number is reached R_*, there is a sharp rise in intensity of convection (presence of weak convection with $R < R_*$ is linked to the use of regularized rheological model (1); in the case of the Shvedov - Bingham medium, the Rayleigh number R_* is the threshold, and there is no convective movement with $R < R_*$; with a decrease in the regularization parameter α, the intensity of convective movement with $R < R_*$ drops). The calculations made with different values of the parameter τ_o indicate that the values of the ratio of the Rayleigh threshold number R_* to the parameter

τ_0 agrees well with those found in [1] using the variational principles.

Zones of quasisolid and viscoplastic flows were conditionally defined from the found fields of current and voltage functions. It was indicated that in the case of the square region, the zone of viscoplastic flow develops with $R \approx R_*$ in a narrow annular layer that on individual sections touches the boundaries of the region. In the case of a square region, the zones of viscoplastic flow develop with $R \approx R_*$ in a narrow layer that touches the edges of the region, and in the central part of the region. The numerically found distributions of deformation velocities and stresses agree qualitatively with those obtained in [1] using variation principles.

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S2.41. Mechanical Equilibrium of Nonuniformly Heated Real Liquid in Reduced Gravitation

A. F. Glukhov and G. F. Putin (Perm')

If a liquid is considered Newtonian and single - phase, then it will be quiescent when the gravitational field $\vec{g}$ and the temperature gradient ∇T are parallel and the Rayleigh number is less than the critical; the horizontal component $\nabla T \sin\alpha$ (α--angle between $\vec{g}$ and ∇T) is as small as desired and excites convective circulation. However, in weak fields, the effects which under terrestrial conditions are small on the background of the gravitational convection mechanism and are associated with deviations in the real liquid from the adopted model ean become decisive. This effect is found in experiments with layers of polar liquids of thickness d from 0.7 to 5 mm in glass blocks, or metal, on the one hand, and glass on the other hand. The layer shifts between the heat exchangers perpendicularly to their surfaces. The component $\nabla T \sin\alpha$ was assigned by

inclination of the heat exchanger from the horizontal in a plane parallel to the broad boundaries [illegible]. The flow was recorded by thermocouples from the deviations from equilibrium temperatures. Their intensity was the average module classified with the temperature difference T of the heat exchangers. The velocities in water were also determined by electrochemical method. With small α, the liquid is quiescent. When the critical angle $\alpha_c(T) \leq 5°$ is exceeded, a flow develops whose intensity is proportional to the inclination. The angles α_c which are found in experiments with different T and D make it possible to introduce criteria of similarity $\tau_c = \rho g \beta T d \sin\alpha_c$, $\tau_c \leq 10^{-2}$ dyne/cm^2. Here ρ and β--average density and thermal coefficient of expansion. The parameter τ_c has the meaning of the initial shear stress, however, its magnitude is lower than the sensitivity of the methods of capillary viscosimetry. In nonpolar benzene, the angle is α_c.

The presence of the critical parameter τ_c for nonisothermic polar liquids under terrestrial conditions is manifest in the finite amplitude Rayleigh instability in thin cells [1]. However, in fields several orders lower than the terrestrial, this effect can stabilize the equilibrium with random directions $\vec{g}$ and ∇T and in cavities of considerably greater thickness.

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SECTION 3. EQUILIBRIUM, STABILITY AND MOTION OF LIQUIDS WITH FREE SURFACES /93

3.1. Solution to Laplace Capillary Equation for Double Bond Axisymmetrical Surfaces by Linearization Method and Its Application to the Problem of Crystallization in Microgravity

I. V. Barmin and A. S. Senchenkov (Moscow)

Double bond liquid surfaces are very important from the viewpoint of applications. Their theoretical study is difficult,

and with the exception of simple situations, a sufficiently effective algorithm for constructing an equilibrium line in this case has not yet been obtained [1, 2]. At the same time, in the majority of essentially interesting cases, the surface shape does not differ strongly from the cylindrical of constant diameter. This circumstance allows us to use linearization of the Laplace capillary equation to solve a large number of problems. As a result of linearization, the equation of equilibrium line r(z) was obtained in an explicit form in the cylindrical coordinate system for fixed and rotating liquid with g-force acting along the axis. The boundary value conditions can vary, i.e., it is possible either to assign the radius at the ends of the examined interval, or the angle of inclination of the tangent at these points.

The computation results for relationships obtained in the linear approximation were compared with the results of the known numerical solutions on the computer of the Laplace original equation [2]. The error in these relationships in the examined cases did not exceed 5% with $|\varepsilon| < 30^{\circ}$ and $0.8 < r_m/R < 1.2$, where ε--angle between the tangent to the equilibrium line and axis, R--characteristic radius, r_m--minimum distance from the axis to the equilibrium line.

The obtained solutionwas used to compute the parameters of crystallization with different methods for growing crystals. The /94
method of zonal melting, Stepanov method and method of directed crystallization in an ampoule is examined. An additional condition which guarantees uniqueness of the solution is assigning the pressure on the edge of the shape former in the Stepanov method and volume v of liquid in the methods of zonal melting and directed crystallization.

The following were obtained, in particular:

--link between parameters of the crystallization process when crystals are grown of constant diameter by the zonal melting method

$$\frac{Bo}{K}\left[\frac{L\sqrt{K}}{2}ctg\left(\frac{L\sqrt{K}}{2}\right)-1\right]-\frac{K(V-L)}{4\left[1-\frac{L\sqrt{K}}{2}ctg\left(\frac{L\sqrt{K}}{2}\right)\right]}+tg\,\varepsilon_o=0; \quad (1)$$

--formula for determining the radius of the crystal grown by the Stepanov method

$$R_k=1-(Bo+tg\,\varepsilon_o)tg\,L-Bo\,L-(P-1)(Sec\,L-1); \quad (2)$$

--condition for formation in weightlessness of a "neck" when the crystal grows in an ampoule

$$\left(1-\frac{a}{2\cos\alpha_o-1}\right)tg\,\alpha_o-\left[2a(2\cos\alpha_o-1)-a^2\right]^{1/2}<tg\,\varepsilon_o, \quad (3)$$

where $Bo=\rho g_o n R^2/\sigma$ --Bond number; $K=1+2We$, $P=(p_o-p_r)R/\sigma$,

$We=\rho\omega^2R^3/2\sigma$ --Weber number.

Formulas (1) - (3) used the following designations: ρ--density, g_o--acceleration of free fall to Earth, n--g-force, σ--coefficient of surface tension, ω--angular velocity of liquid rotation, a--gap between crystal and ampoule, α_o--angle, supplemental to wetting angle, R_k--radius of crystal, L--length of liquid column, p_r--gas pressure, p_o--pressure in melt at edge of shape - former, ε_o--growth angle. All the quantities in the formulas are dimensionless. The following are adopted as the characteristic dimensions: radius of the initial material in the method of zonal melting, radius of shape former in the Stepanov method, inner radius of the ampoule in the method of directed crystallization.

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3.2. Problems of Liquid Equilibrium Stability with Unbonded Free Surface in Open Systems

L. A. Slobozhanin (Khar'kov)

A study is made of the stability of the equilibrium condition, where the liquid partially fills the vessel and its free surface Γ consists of m connected components $\Gamma_i (i = 1, \ldots, m; m > 1)$. It is assumed that the areas occupied by gas are interconnected or with unlimited space. The liquid has surface tension and is exposed to the effect of a weak field of mass forces.

A feature of the problem for comparison with the case of connected Γ is expansion of the class of permissible perturbations for each of the Γ_i. It is demonstrated in examining the analog of the Maxwell task where the liquid is on a plate with several of the same openings of rectangular shape, while Γ_i are flat. A study was made of the stability of liquid equilibrium in a gravitational field if the vessel in the vicinity of each of the wetting lines γ_i (i = 1.2) is cylindrical (in this case, the shapes and dimensions of the cross sections for the corresponding cylinders do not mandatorily coincide). The answer depends on the arrangement of the liquid in relation to the direction of the gravitational forces and on the ratio of cylinder cross section areas.

With the assumption of axial symmetry, the possibility is discussed of studying stability by constructing a critical surface in the space of parameters χ_i defined by the value of the wetting angle, as well as curvatures of the vessel surface and Γ_i on the line γ_i (i = 1, ..., m). An examination was made of a number of tasks for m = 2. In particular, boundaries were constructed for the maximum region of stability in weightlessness and under the /96

influence of the gravitational field (in the latter case Γ_i are considered flat).

The task is formulated for a system made of several immiscible liquids with free surfaces.

3.3. Electrodynamics of Weightlessness Conditions

I. M. Kirko (Perm')

1. Electrostatic and magnetostatic equilibriums in weightlessness. Irnshaw theorem and its interpretation. First works of V. K. Arkad'yev. Ponizovskiy experiments. Model of the Earth's hydrosphere. Creation of artificial gravity using an electrical field.

2. Transitional states of liquids in weightlessness with regard for ion conductance and microstates of ferroliquids. Failure of certain electrostatic experiments in weightlessness. Separating properties of an electrical field in future space technologies. "Decisive experiment" in ferrohydrodynamics, detection of claster condition of ferromagnetic liquids.

3. Ratios of electrodynamic and capillary equilibrium in weightlessness. Dynamics of the skin effect in liquid metals. Wall-less pipes. Sterile transport in space technology.

3.4. Control of Stability of a Liquid Surface Using Variable Fields

V. A. Briskman (Perm')

This report examines the effect of variable fields of different physical nature (electrical, magnetic, gravitational on stability of equilibrium in a liquid mass with free surface. /97
General laws were established for the development of instability linked to modulation of the fields in time. Results are presented of analysis and experimental verification of the known [1, 2, and others] and new mechanisms for modulation (parametric) instability.

It was indicated that through field modulation one can have a significant stabilizing or destabilizing effect on the free surface. The use of control without feedback is substantiated in situations where the research results permit a guaranteed maintenance of the necessary stability mode in the parameter range necessary for practical purposes.

Laboratory experiments are described in which conditions are stabilized that are absolutely unstable in the absence of a controlling factor. For example, results are presented of experiments to prevent Rayleigh - Taylor instability using vibrations and variable tangential electrical field.

The proposed method of controlling stability can be used, in particular, to stabilize the free surface of the melts in the space technology processes.

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3.5. Laboratory Modeling of Stability and Resonance Oscillations of Liquid Zones with Small Bond Numbers

M. P. Yelagin, A. P. Lebedev, A. V. Shmelev (Moscow)

Development of liquid formation processes, crucibleless growth of crystals, and so forth for weightlessness makes it necessary to develop methods of laboratory and mathematical modeling of hydromechanics for free liquid zones.

This work examines different methods for laboratory modeling of certain capillary phenomena in isothermic conditions: with a /98
decrease in the characteristic size ("microprobe" method) and with the use of hydrostatic forces for buoyancy of immiscible liquids of equal density ("neutral buoyancy" method). Experimental

data are presented on shapes and stability of spherical, cylindrical and conical equilibrium surfaces. A comparison is made with the theoretical data [1].

The "microprobe" method studies the resonance oscillations in the liquid zones. Experimental data were obtained on the natural oscillations depending onthe shapes of the spherical, cylindrical and conical zones. A comparison is made with the theoretical data obtained for small oscillations in the column of liquid on an unrestricted plane [2].

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S3.1. Equilibrium Figures for Rotating Drop in Weightlessness

L. A. Slobozhanin (Khar'kov)

Study of the classic problem of equilibrium figures of a rotating weightless free drop of viscous liquid which has surface tension has more than independent importance. It is important also for other fields of science (for example, in modeling an atomic nucleus), and for technology. Solution to this problem permits control of the drop and is the basis for studying subsequent problems of pressure by additional application of external force fields (electrical, magnetic, etc.). Consequently, publication [1] discusses the program of experiments on a returnable space vehicle for observing the evolution of shape in a rotating drop.

Theoretical studies of axisymmetrical equilibrium figures and their stability have been previously made by J. Rayleigh, P. Apple, S. Chandrasekhar and the author. This publication /99

studies branching of the solutions to the nonlinear equilibrium problem (the expediency of this study has been noted in [1, 2]). It was established that a two - parametric family of nonaxisymmetrical states which are invariant in relation to rotations around the rotation axis z passes through the critical (in the sense of stability) axisymmetrical state. In this case, the deviation in the free surface of the new family from the critical axisymmetrical surface Γ_* on the perpendicular to the latter for values of the parameter p close to the critical p_* looks like

$$\dot{\mathcal{N}} = 0.946\sqrt{|p - p_*|}\, u(s) \sin 2(\varphi + \mathrm{const}) + O(|p - p_*|).$$

Here $p = \rho\omega^2/2\sigma$; ρ, σ --density and coefficient of surface tension of liquid; ω--angular velocity of uniform rotation around the z axis; $p_* = 5.253\ V^{-1}$; V--volume of liquid; ϕ--polar angle in cyclindrical coordinate system r, ϕ, z; s--length of the section arc Γ_* counted from the pole with plane ϕ = const; u(s)--limited solution to the following equation having symmetry in relation to the straight line $s = \tau$ (τ--value s at the equatorial point)

$$u'' + \frac{r'}{r}u' - \left(2p_* r z' - \frac{z'^2}{r^2} - r''^2 - z''^2 + \frac{4}{r^2}\right)u = 0,$$

for which $u(0) = u'(0) = 0$, $u''(0) = p_*^{-1/6}$, r(s), z(s)--coordinates of point for Γ_*.

It is indicated that branching occurs towards $p < p_*$. However, for the branching figures, the kinetic moment μ in relation to the z axis is larger than its critical value $\mu_* = 4.443\sqrt{\rho\sigma}\, p_*^{-7/6}$. The branching nonaxisymmetrical figures are stable near the branching point. Consequently, with $\mu > \mu_*$, nonaxisymmetrical equilibrium figures and only these may be observed.

The findings together with the previous studies on axisymmetrical equilibrium forms and their stability prove the remarkable similarity in the behavior of the rotating liquid masses that

are held by the forces of surface tension and the gravitational forces.

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S3.2. Margin of Stability of Equilibrium States for Flat and Axisymmetrical Drops

M. A. Svechkareva (Khar'kov)

The functional minimum $U(\gamma)$ of potential energy in the examined system is realized on stable equilibrium states of a free liquid surface γ_o.

The concept of potential depression for the given condition γ_o of stable equilibrium was introduced in publication [1]. The potential depression is delimited by a stationary point (if it exists) for the functional of potential energy $U(\gamma)$, the equilibrium form of γ_n which is closest to γ_o in $U(\gamma)$ values. We call this the "cross-over" form. Then the stability margin H (depth of potential depression) is defined as the difference in values

$$H = U(\gamma_n) - U(\gamma_o). \quad (1)$$

Stable equilibrium forms of the free flat surface of a flat and axisymmetrical drop have been well studied [2, 3]. Boundaries for the area of stability of symmetrical or axisymmetrical equilibrium forms have been constructed in the plane of change in the parameters of the problem, angle of wetting α and area of cross section Q or volume V. It is also indicated [2, 3] that the most dangerous (minimum of second variation in the potential energy functional is nullified) are the symmetrical for the flat and axisymmetrical for the spatial perturbation problems. This allows us to hypothesize that the equilibrium form γ_n which lies

on the boundary of the potential depression for X_o is an unstable symmetrical or axisymmetrical equilibrium form. /101

By using the properties of the integral curves for the equilibrium system equations and the physical considerations, one can construct the unknown unstable "cross-over" forms γ_n in a similar way as this was done in publication [4]. These constructions are possible for values of parameters from a certain finite region that adjoins the boundary of stability. This region can be obtained as follows.

For each integral curve of the equilibrium equation we note in the plane for change in problem parameters those points (α, Q or V) for which one can state solutions from the selected integral curve. Doing this for all the integral curves, we obtain a certain subregion in the region of stability, for each point of which (α, Q or V) there are no less than two solutions, one of which is stable. Figure 1 presents the plottings for the flat drop. It is obvious that for each point in the area ABCDEA there are two solutions which correspond to different integral curves defined by the initial values Y_o. Formula (1) is used to easily compute the precise margin of stability for each point in region ABCDEA. Figure 2 presents lines for equal stability margins for a flat drop. Similar results were obtained for the axisymmetrical drop.

The stability margin H can be viewed as an accurate evaluation from above of the kinetic energy which can be attributed to the system in condition γ_o so that it remains in the corresponding γ_o potential depression.

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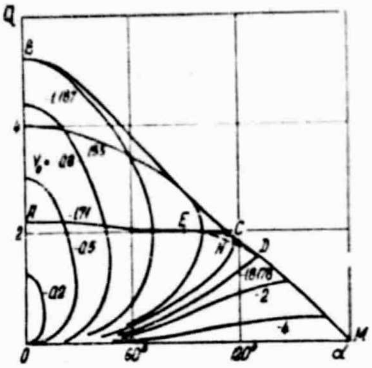
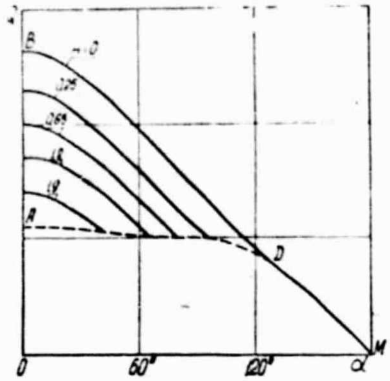


Figure 1.



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S3.3. Forms of Equilibrium in a Capillary Liquid between Two Rings (Pipes)

V. M. Yentov and A. L. Yarin (Moscow)

The problem of forms of equilibrium of liquid films (drops) which are between two rings (pipes) with different pressures inside the liquid p is solved. Values are defined for the distances L between the rings (pipes) at which the stationary solution for the assigned pressure does not exist. Regions are set on the plane p - L in which there are one, two and three equilibrium configurations.

S3.4. Approximate Analytical Methods of Solving the Problem of Liquid Hydrostatics in a Vessel under Conditions Close to Weightlessness. Small Perturbations of Stable Equilibrium Forms /104

M. Ya. Barnyak and I. A. Lukovskiy (Kiev)

An examination is made of the vessels which have the shape of a rotation body with symmetry axis parallel to the effect of

the gravitational force, as well as cylindrical vessels of random cross section.

Analytical methods are proposed for solving the task of the shape of equilibrium of the free liquid surface in these vessels with consideration for the surface forces. The axisymmtrical equilibrium forms of the free liquid surface are described by the following system of nonlinear differential equations

$$\begin{cases} r'' = z'\left(br - \frac{r}{2}\right), \\ z'^2 + r'^2 = 1, \end{cases} \tag{1}$$

where z = z(s), r = r(s)--parameteric form of assigned curve; s--length of arc; (') designates differentiation for s; b--Bond number.

In addition to the system of differential equations (1), functions z(s) and r(s) should satisfy the corresponding boundary value conditions. Solution to the Cauchy problem for system of equations (1) is constructed in the form of exponential series

$$z = \sum_{k=0}^{\infty} a_k s^k, \quad r = \sum_{k=0}^{\infty} b_k s^k. \tag{2}$$

In this case recurrent formulas were obtained for the coefficients a_k and b_k. The formulas reflect each subsequent coefficient a_{k+1} and b_{k+1} through all the preceding. An evaluation is made of the convergence of series (2). The question of stability of the constructed equilibrium forms is studied. Because solution to problem (1) is presented in an analytical form, an effective criterion is constructed for evaluating stability of the equilibrium forms. For stable equilibrium forms, an examination is made of the problem with small perturbations in the equilibrium form, as a consequence of small changes in the geometric dimensions of the vessel and the

Bond number. Green function of the boundary value problem is constructed for this purpose for the corresponding linear differential equation of the second order. It is also important to use the method of exponential series to solve this problem.

In the case of cylindrical regions (including inclined), there is reason to construct a solution to the problem of hydrostatics through minimizing the functional

$$K(f) = \int_G \left[\left(1 + \left(\frac{\partial z}{\partial x} \right)^2 + \left(\frac{\partial z}{\partial y} \right)^2 \right)^{1/2} + \frac{B}{2} \left(z\alpha_3 + x\alpha_1 + y\alpha_2 \right)^2 \right] dG - \int_l \cos \gamma z \, dl, \tag{3}$$

where G--cross section of the cylinder with plane z = const; (α_1, α_2, α_3)--guide cosines of the gravity force action vector; $z = z(x, y)$--equation of free liquid surface; γ--angle of wetting by liquid of the solid cavity wall.

It was indicated that the functional (3) is defined in the Sobolev space $W'_1(G)$. The approximate solution is presented in the form

$$z = \sum_{k=1}^{N} a_k \psi_k(x, y), \tag{4}$$

where $\{\psi_k(x, y)\}$ --certain complete system of functions in $W_1'(G)$.

The coefficients a_k are defined from the conditions for the minimum funtional (3). The Newton method is used to solve the corresponding system of nonlinear algebraic equations. Numerical examples are given.

S3.5. Stability of a Stream and Threads of Nonewtonian Liquids /105

Z. P. Shyl'man and B. M. Khusid (Minsk)

An examination is made of the breakdown of capillary streams

of nonlinear viscous and nonlinear viscoelastic liquids. Solution (1) to the problem in the long wave approximation $(\partial R/\partial z)^2, R\partial^2 R/\partial z^2 \ll 1$ without consideration for the inertia terms was obtained in Lagrange variables $\theta = t, \xi = \int_z^{L(z)} \pi R^2 dz$, $dL/dt = V(L,t)$ where ξ equals the volume of liquid between the sections z and L(t); R--radius of stream, V--velocity of liquid, the 0z axis coincides with the stream axis. The z = 0 section was taken as the zone of reconstruction for the velocity profile and relaxation of stresses: here $R|_{z=0} = R_0$

$$\sigma(\xi,\theta)\pi R^2(\xi,\theta) + \pi æ R(\xi,\theta) = \pi æ R_0, \quad \frac{\partial V}{\partial z} = -\frac{2}{R}\,\frac{\partial R}{\partial \theta}, \tag{1}$$

where σ--longitudinal tension in stream, æ --surface tension of liquid. In (1) ξ is included only as a parameter in the magnitude of perturbation of the radius: $R|_{\theta=0} = R_н(\xi)$. . The perturbation in each section develops independently, moving together with the liquid. Substitution of (1) into the rheological equation of liquid for uniaxial extract provides an equation for development of perturbations. For the nonlinear viscous liquid

$$-\frac{2}{u}\,\frac{\partial u}{\partial \tau} = f(u)\,\mathrm{sign}(1-u), \qquad u|_{\tau=0} = u_н(\xi).$$

Here:

$$u = R/R_0, \quad \tau = \theta/\theta_*, \quad \theta = 1/\Phi(æ/R_0),$$
$$u_н(\xi) = R_н(\xi)/R_0, \quad f(u) = \Phi(æ/R_0, |1-u|/u^2)/\Phi(æ/R_0),$$

$|\sigma|/\Phi(|\sigma|)$ --longitudinal viscosity of liquid. For the Newtonian liquid:

$$u(\xi,\tau) - u_н(\xi) + \ln\left|\frac{1-u(\xi,\tau)}{1-u_н(\xi)}\right| = \frac{\tau}{2}$$

In the case of the maximum dilatant liquid, a system of drops is formed at the sites of the maximum value $R_H(\xi)$ connected by threads that become thinner with essentially constant rate. The stream of maximum pseudoplastic liquid is broken down into columns at the sites of the minimum value $R_H(\xi)$. For nonlinearly viscoelastic liquid with rheological equation of the Oldroid type: /106

$$\frac{1-u}{u^2} = q - \frac{(1-\alpha)\omega}{u}\frac{\partial u}{\partial \tau}, \quad u|_{\tau=0} = u_H(\xi), \quad q|_{\tau=0} = q_H(\xi),$$

$$q + \frac{\partial q}{\partial \tau} + \frac{4aq}{u}\frac{\partial u}{\partial \tau} = -\frac{\alpha\omega}{u}\frac{\partial u}{\partial \tau}, \quad \text{with} \quad \frac{\partial u}{\partial \tau} < 0,$$

$$q + \frac{\partial q}{\partial \tau} - \frac{2aq}{u}\frac{\partial u}{\partial \tau} = -\frac{\alpha\omega}{u}\frac{\partial u}{\partial \tau}, \quad \text{with} \quad \frac{\partial u}{\partial \tau} > 0.$$

Here: $\tau = \theta/\lambda$, λ--relaxation time, $\varkappa/R_0 q$ --stress of the Maxwell element, $0 < \alpha < 1$--contribution of the Maxwell element to effective viscosity of the liquid, a--model parameter, $\dot{\omega} = 6\eta R d\hat{\lambda}\varkappa$ determines the ratio between the module of liquid elasticity η/λ and capillary pressure in the stream. The phase plane of this system is divided by the line $q = (1 - u)/u^2$ into two regions. In region I: $q < (1 - u)/u^2$ we have

$$u^{1-4a}\frac{\partial \psi}{\partial u} = -\omega\frac{\alpha(1-\alpha)u^{4a-2} - \psi}{(1-u)u^{4a-2} - \psi}, \quad q = \frac{\psi}{u^{4a}}, \quad \frac{\partial u}{\partial \tau} < 0;$$

In region II: $q > (1 - u)/u^2$ we have

$$u^{2a+1}\frac{\partial \varphi}{\partial y} = -\omega\frac{\alpha(1-u) - \varphi u^{2a+2}}{1-u-\varphi u^{2a+2}}, \quad q = \varphi u^{2a}, \quad \frac{\partial u}{\partial \tau} > 0.$$

In I, all the trajectories approach $\psi = 0$, $u = 0$, and in II, $\psi = 0$, $u = \infty$, asymptotically approaching two maximum curves. The elastic properties of the liquid qualitatively alter the nature of stream breakdown with $\omega \lesssim 1$. In this case, a system of drops is formed which are connected by thin threads that become longer at a rate of $1/(2a - 1)\lambda$ which is considerably shorter than the initial rate of development of small perturbations. The calculation results agree with the published experimental data on breakdown of suspensions (nonlinearly viscous) and diluted solutions of high - molecular

polymers in a viscous solvent (nonlinearly viscoelastic).

S3.6. Equilibrium of a Gas Bubble in an Electrostatic Field /107

V. A. Semenov (Perm')

Conditions were studied under which the air bubbles in toluene are held by electrostatic forces in a fixed position in the volume between two horizontal electrodes, in which a hole is drilled in the lower one.

A variable electrical field with frequency 150 Hertz was created to reduce the effect of electroconvection in the experiments. In light of the low electrical conductivity of toluene ($\sigma \sim 10^{12}$ 1/cm x m) and short distances between the electrodes ($h \sim 1$ cm), one can consider the field to be electrostatic.

It has been indicated that the equilibrium conditions of the gas bubbles do not depend on their diameter, but are completely determined by the geometric parameters of the experimental unit and the electrophysical properties of toluene. The difference in the potentials under which equilibrium is disrupted is directly proportional to the distance between the electrodes and depends on the diameter of the hole by the root law.

A quantitative comparison was made of the theory and experiment results.

S3.7. Stabilization of Gas Bubble Equilibrium Position by an Electrical Field

I. I. Iyevlev and A. B. Isers (Khar'kov)

In weightlessness, a fixed gas bubble acquires a spherical shape under the influence of surface tension forces. When the gravitational field is applied, this bubble is moved and changes its shape. If the bubble is in a liquid dielectric, then using an electrical field of the corresponding configuration one can simulate the weightlessness conditions, i.e., despite the effect of the

gravitational field, the bubble will be quiescent and have a spherical shape. /108

The following task is formulated: find that distribution of potential U of the electrical field on the assigned surface S which encompasses the liquid with the bubble so that with joint effect of the electrical field created by the potential U, uniform gravitational field and surface tension forces, the bubble will be quiescent and preserve its spherical shape. The set problem is solved in two stages.

We initially find the distribution of potential Φ and its normal derivative on the surface of the bubble Γ. Using the boundary conditions for Γ for Φ and stress tensor, the problem of searching for density μ of potential Φ is reduced to the problem of searching for the minimum of a certain quadratic function from μ and c, where c is the constant determined by the norming of Φ.

After determining μ, and consequently, Φ and its normal derivative for Γ, the unknown potential U is defined. This problem is the Cauchy problem for the Laplace equation and refers to the class of incorrect problems. Its solution is reduced with the help of the Green formula to a solution to the integral equation of the first order in relation to a certain auxiliary function, which, in turn, is solved by the method of regularization of A. N. Tikhonov [1].

For the case where S is a sphere that is concentric with the bubble, a numerical calculation was made by the constructed algorithm.

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S3.8. Stability of a Nonconducting Dielectric Drop in an Electrical Field

L. N. Popova and A. I. Fedonenko (Khar'kov)

An examination is made of the stability of equilibrium in a drop of nonconducting liquid dielectric in an electrical field that is uniform for infinity. The dielectric permeabilities of the drop ε_1 and the medium surrounding it ε_2 are considered constant. /109

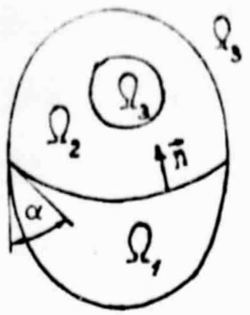
On the assumption that the shape of the drop is close to spherical, it is indicated that with $\gamma = \varepsilon_1/\varepsilon_2 > 1$, the electrical field has a destabilizing effect on the drop behavior. A dependence was found of the dimensionless number $F_* = \varepsilon_2 E_*^2 R/\alpha$ of the corresponding critical situation of stability loss on the parameter γ (R--drop radius, α--coefficient of surface tension on the drop surface).

The critical value of electrical field intensity E_* was experimentally determined for drops of such liquids as water, glycerine, nitromethane, diethylene glycol and N-N-dimethyl formamide suspended on the electrode of the flat horizontal capacitor. A satisfactory qualitative coincidence of the theoretical relationship $E_*(R) = (\alpha F_*/\varepsilon_2 R)^{1/2}$ with the experimental results was obtained.

S3.9. Stability of Equilibrium Forms of Magnetized and Polarizing Capillary Liquids

I. D. Borisov (Khar'kov)

Based on the principle of minimum potential (free) energy, a study was made of the stablity of the equilibrium states of a nonconducting liquid exposed to the effect of a constant magnetic or electrostatic field, forces of surface tension and gravitational forces. According to this principle, the equilibrium free surface Γ is a stationary point of the surface energy functional, so that $\delta\mathcal{F}(\Gamma,\mathcal{N}) = 0$, and one can judge the stability by the sign of the second variation $\delta^2\mathcal{F}(\Gamma,\mathcal{N})$ (N--deviation of the perturbed free surface from Γ which is counted on the perpendicular $\vec{n}$ to Γ).



The question of the sign of the second variation was reduced to studying the sign of the least natural value λ^* of a certain linear boundary value problem. In the case of a magnetizing liquid, this problem (in relation to $\mathcal{N}, \varphi, \eta = \mathrm{const}, \lambda$) looks like: /110

$$\Gamma: -\sigma\Delta_\Gamma \mathcal{N} + c\mathcal{N} + \left\{B_n \frac{\partial\varphi}{\partial n} + \mu_0 \mu' H_n^2 (\vec{e}_H \cdot \nabla\varphi) - \vec{B}_\tau \cdot \nabla_\Gamma \varphi\right\}_\Gamma + \eta = \lambda\mathcal{N},$$

$$\gamma: \frac{\partial \mathcal{N}}{\partial \nu} + æ\mathcal{N} = 0, \qquad \int_\Gamma \mathcal{N} d\Gamma = 0;$$

$$\Omega_i: \mathrm{div}\left[\mu_i \nabla\varphi^{(i)} + \mu'(\vec{e}_H \nabla\varphi^{(i)})\vec{H}^{(i)}\right] = 0, \quad (i = 1, 2, 3);$$

$$\Gamma: \{\varphi\}_\Gamma = \{H_n \mathcal{N}\}_\Gamma, \quad -\mu_0\left\{\mu \frac{\partial\varphi}{\partial n} + \mu'(\vec{e}_H \cdot \nabla\varphi) H_n\right\}_\Gamma = \left\{\mathrm{div}_\Gamma (\vec{B}_\tau \mathcal{N})\right\}_\Gamma;$$

$$S_{ij}: \{\varphi\}_{S_{ij}} = 0, \quad \left\{\mu \frac{\partial\varphi}{\partial n} + \mu'(\vec{e}_H \cdot \nabla\varphi) H_n\right\}_{S_{ij}} = 0, \quad (ij = 13, 23)$$

$$\varphi^{(3)}(\vec{x}) \to 0 \text{ with } |\vec{x}| \to \infty;$$

$$c = -\sigma(k_1^2 + k_2^2) + \rho \frac{\partial \Pi}{\partial n} + \left\{B \frac{\partial H}{\partial n} - \frac{\partial}{\partial n}(H_n B_n)\right\}_\Gamma; \quad \mu_i'(H) = \frac{d\mu_i(H)}{dH};$$

$$\vec{e}_H = \frac{\vec{H}}{H}; \quad æ = \frac{k_s + k_\Gamma \cos\alpha}{\sin\alpha}; \quad \Delta_\Gamma(\cdot) = \mathrm{div}_\Gamma[\nabla_\Gamma(\cdot)].$$

Here $\vec{H}(\vec{x}), \vec{B}(\vec{x})$ --intensity and induction of the magnetic field in an equilibrium condition; $\varphi(\vec{x})$ --potential of perturbation of the magnetic field; μ_0--magnetic constant; $\mu_i (i = 1, 2, 3)$ --magnetic permeability of the i-th medium; σ--coefficient of surface tension for Γ; ρ--density of liquid; α--angle of wetting; $\Pi(\vec{x})$ --potential of gravitational field; γ--contour of intersection of the vessel surface S and surface Γ; k_1, k_2--main curvatures of surface Γ; k_Γ, k_s-- curvatures of surface sections Γ and S by plane perpendicular to γ; $\vec{\nu}$ --perpendicular to γ lying in the plane tangential to Γ; S_{ij}--interface of i-th and j-th media; Δ_Γ--Laplace

Beltram operator; $\{a\}$--jump in the quantity a by Γ; the meaning of the remaining designations is clear from the figure. /111

The equilibrium condition of the magnetizing liquid is stable if $\lambda_* > 0$, and unstable if $\lambda_* < 0$.

Similar examinations were made for the polarizing liquid in an electrostatic field.

A study was made of the stability of axisymmetrical forms of liquid equilibrium contained between two horizontal plates in a magnetic field that was created by a current flowing through a vertical cylindrical conductor, and also stability of a spherical field of a weightless polarizing liquid.

S3.10. Stabilization of the Liquid Interface by an Electrical Field

L. N. Kisov and M. T. Sharov (Perm')

In space technology (different conditions of melting, transporting liquids, etc.) it becomes necessary to stabilize the shape of the liquid interface, which for liquid dielectrics can be attained using a uniform tangential electrical field [1]. An experimental study was made of stabilization by variable field of unstable equilibrium in a heavy liquid above air (Rayleigh - Taylor instability). In order to weaken the effect of electrical conductivity of a liquid, the field frequency was selected to be greater as compared to the opposite relaxation time of the electrical charge in the liquid.

The transparent model had a vertical channel in the form of a slit with two parallel broad walls and rectangular cross section. The narrow walls were arranged symmetrically to the channel axis at a small angle to the vertical, therefore the size of the wide walls increased linearly from top to bottom. At the top, the channel section had the shape of a square whose side was smaller than the capillary constant. Below, the distance between them (size of the wide walls) significantly exceeded this constant. The model was

secured between the flat vertical electrodes, perpendicular to the wide walls. /112

The liquid (diethyl ether) was fed very slowly into the channel from the top. The liquid - air interface was gradually shifted downwards, and its size ℓ along the wide channel wall increased. In the absence of the electrical field, until the dimension ℓ exceeded a certain critical value ℓ^*, stability of the interface was guaranteed by surface tension. With $\ell = \ell_*$, Rayleigh - Taylor instability occurred. In an electrical field, stable equilibrium also occurred in the interval of values where the quantity ℓ_E increased as the intensity amplitude increased (with E = 20 kV/cm, the quantity ℓ_E was roughly double that of the capillary constant).

Suppression of perturbations extending along the vector of field intensity was observed in the experiments. In order to suppress the randomly oriented perturbations, a rotating electrical field can be used [2, 3]. It should be noted that the studied effect differs from the known phenomenon of stabilization of the interface in strongly heterogeneous fields [1].

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S3.11. Control of Stability of a Free Liquid Surface by Variable Fields

V. A. Briskman, D. V. Lyubimov and A. A. Cherepanov (Perm')

In certain problems of space technology, the problem arises of controlling the stability of a free liquid surface (or liquid

interface). This control can be implemented by variable fields of different physical nature (gravitational, electrical and magnetic). These fields under definite conditions can both stabilize and destabilize the liquid surface. /113

1. Stabilization of the liquid surface. With accelerations of the space vehicle directed towards the heavier liquid, the surface can become unstable, as a consequence of the development of Rayleigh - Taylor instability. This instability can be suppressed after including vibrations of the vessel with liquid in a direction perpendicular to its surface. In this case the instability will be suppressed if the vibration frequency exceeds a certain limit (depending on the properties of liquid and the vessel dimensions), while the amplitude of vibrations is fairly high. Since parametric waves can develop with large vibration amplitudes on the liquid surface, the amplitude of the vibrations must be limited from above as well. The interval of amplitudes in which the Rayleigh - Taylor instability can be suppressed rises with vibration frequency. For dielectric liquids with large dielectric permeability, the use of tangential rotating electrical field can prove effective, and for conducting liquids, a tangential rotating magnetic field. In the latter case, stabilization is especially effective if the liquid is on a good conducting backing. As with vibrations, stabilization occurs at frequencies that exceed a certain critical value, and the amplitude of the fields must be limited both from above and from below.

2. Surface destabilization. The variable external fields can be used for destroying the free liquid surface as well. If the amplitude of vibrations in the vessel with the liquid are perpendicular to its surface, and a certain threshold is exceeded, parametric waves develop on the liquid surface. It follows from the linear theory that the threshold of their development is determined by the viscosity of the liquid. The nonlinear calculation shows that the viscous vortex skin layer has a strong effect on the

development of parametric waves. With small supercriticalities, a relief is formed of standing waves which with further rise in the amplitude of vibrations become breakdown - unstable (regardless of the relief shape). A unique wave turbulence develops: the appearing standing waves are immediately broken down into resonance pairs. Further increase in the vibration amplitude results in a disruption in surface continuity: drop fountain effect begins. A similar effect can be implemented using an electrical field that is /114
perpendicular to the liquid surface (both dielectric and conducting). In the latter case it is necessary to see that the strong twisting of the liquid surface does not result in flash-over. Since the size of the drop strongly depends onthe frequency of vibrations (or field rotation), then by changing the frequency, one can control the dimensions of the drop.

S3.12. Inversion of Stable Stratifications of Liquid - Gas under the Influence of Vibrations (Experiment)

N. A. Bezdenezhnykh (Perm')

A study was made of the effect of vibrations on the stability of the liquid interface when there is an acceleration perpendicular to this surface. Conditions of similarity of the experiments on Earth and in space were formulated.

Modeling on Earth revealed a new mechanism of inversion under the influence of vertical vibrations of usually stable stratifications, gas on top of liquid. The phenomenon is realized as follows. The liquid was initially poured onto the bottom of the vessel attached to the vibration stand. With an increase in the vibration amplitude, parametric instability of the interface develops. It results in the formation of standing waves, and the nonlinear development and wave instability result in a fountain effect in the drops. As a result of the fountain effect, the liquid under definite conditions can collect on the cover of the container. A liquid - gas - liquid structure is thus formed in the container, and the upper and lower layers are in dynamic equilibrium, interchanging in fountains. Selection of parameters can attain stable

equilibrium of the entire structure with flat interfaces.

The experiment also realized another variant of inverted stratification in which the layer of liquid in the vessel was limited from above and from below by air layers. This liquid - gas - liquid structure is obtained by filling the vessel from above, making vertical oscillations with definite velocity. In this case portions of liquid and gas are successively fed into the vessel. /115

The experimental results correspond to the theory [1].

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S3.13. Parametric Instability of the Surface of a Liquid Flowing Out of a Vessel

V. G. Nevolin (Perm')

It is common knowledge that oscillations in liquid fuel in tanks and pipelines have a great effect on the dynamics of liquid propellant rockets as well as other moving vehicles. Thus, the longitudinal oscillations in rockets result in the fact that waves are excited on the liquid surface in the tanks, which with a rise in amplitude of vibrations become unstable and are destroyed, forming sprays made of liquid drops. In this case it is possible for the liquid to trap the gas (gasification of fuel) [1]. Suction of gas into the liquid can significantly alter the hydrodynamic characteristics of the flow through the tank and the pumping system connected to it, which in the final analysis results in different types of emergency situations [2].

Thus, the problem develops of excitation and suppression of waves on the surface of a vertically oscillating tank, in the case where the reservoir is filled with liquid or is emptied.

1. Assume that the nonviscous liquid of density ρ with coefficient of surface tension α occupies part of the cylindrical

vessel of random cross section to height h and flows through the bottom at a rate of $\dot{h}$. The vessel makes scillations along the vertical axis according to the law $a\cos\omega t$, where a--amplitude, ω--frequency of vessel vibrations.

The examination was made in the linear statement in a Cartesian coordinate system, whose plane (xy) coincides with the unperturbed liquid surface, while the z axis is directed vertically upwards. Then in the coordinate system that is moving together with the vessel, the equations are written normally; it is only necessary /116 to introduce effective acceleration $\vec{g}(t) = (0, 0, a\omega^2\cos\omega t)$.

By solving the Navier - Stokes equation with the corresponding conditions on the surface of the liquid and the bottom of the vessel, and by selecting as the measurement unit the length, time , velocity and pressure respectively $(\alpha/L)^{1/2}, (\alpha\rho^2/L^3)^{1/4}, (\alpha L/\rho^2)^{1/4}$ and $(\alpha L)^{1/2}$ we obtain for the surface shifting ζ from the equilibrium position the following equation

$$\ddot{\zeta} \pm (\delta_1 + \delta_2)\dot{\zeta} + \operatorname{th} kH\,(\Omega_0^2 \pm k\ddot{H} - bk\cos\bar{\omega}t)\zeta = 0, \qquad (1)$$

where $\delta_1 = k\dot{H}\operatorname{th} kH$; $\delta_2 = 2k\dot{H}/\operatorname{sh} 2kH$; $b = \rho a\omega^2/L$; $\Omega_0^2 = k^3 + k$;
k--wave number; $H = h/(\alpha/L)^{1/2}$, $\bar{\omega} = \omega/(L^3/\alpha\rho^2)^{1/4}$ --dimensionless height of the layer and frequency of vibrations; L--drop in pressure. The plus sign corresponds to the case of vessel filling, and the minus sign--to flow from the vessel.

Equation (1) is the Mathieu equation with damping [3]. By solving it near the main resonance $\Omega_0^2 \pm k\ddot{H} = \bar{\omega}/2$ on the assumption that $\dot{H}$ = const and kH > 1, we find that in the case of filling the vessel, waves appear on the surface with wave number k with $b > \bar{\omega}\dot{H}$. In the case of flow of the liquid, its surface is unstable.

2. We will examine the case where the vessel vibrations are missing, i.e., b = 0, and the liquid level fluctuates near the equilibrium position according to the harmonic law $H = H_0 + d\cos\bar{\omega}t$.

Then we can write from equation (1) on the assumption that kH > 1 for ζ the following

$$\ddot{\zeta} - kd\bar{\omega}\dot{\zeta}\sin\bar{\omega}t + (\Omega_0^2 - kd\bar{\omega}^2\cos\bar{\omega}t)\zeta = 0. \qquad (2)$$

By solving this equation near the main resonance, we obtain for the boundaries of the region of instability

$$d = \pm 2(\Omega_0^2/\bar{\omega}^2 - 1/4)k.$$

Thus, modulation of the liquid level in the vessel can also result in a parametric excitation of waves on the surface.

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S3.14. Parametric Instability of Liquid Films

V. G. Nevolin (Perm')

Because of problems of space technology, and namely, in relation to possible production of foam materials in weightlessness using variable effects [1], the problem arises of parametric instability and stabilization of liquid films, since in order to obtain materials with macropronounced porous structure it is necessary for crystallization (of foam metals) or hardening of materials to occur from the state which is liquid films that are oriented in a diverse manner in space.

An examination is made of the problem of stability of a liquid layer with free boundaries in the following two cases: a) the film is covered with a layer of insoluble surfactant and is exposed to the effect of vibrations; b) an electrical field oscillating with frequency ω is applied to the layer surface.

The examination was made for the case of thin films, i.e., with regard for the Van der Waals forces, and the thick films with regard only for the capillary forces. If there is no variable effect, the thick walls are stable, since the natural frequency of oscillations in the film surface is positive, and the thin films may be unstable because of the Van der Waals compression (with small values of the wave number $\omega_o^2 \leq 0$).

The variable effect results in parametric excitation of the surface waves, when the excitation frequency is close to $2\omega_o$, ω_o, $2\omega_o/3, \ldots$

Since the natural oscillation frequency in the surface of thin films with small wave numbers can be negative, dynamic stabilization is possible in this system [2].

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S3.15. Parametric Excitation of Oscillations in the Free Surface of a Magnetic Liquid

G. E. Kron'kalns, M. M. Mayorov, A. O. Tsebers (Riga)

It is common knowledge that the effect of external fields radically alters the condition of free surfaces of the magnetizing and polarizing liquids. This report presents results of studying the parametric build-up of oscillations on the free magnetic liquid surface (ML).

1. Analysis of the equation for shifts in the free ML surface in a tangential variable magnetic field $\vec{H}_0 = (H_0 \cos \omega t, 0, 0)$ shows that with $H_0^2 > 32\pi\eta\omega(\mu+1)/(\mu-1)^2$ a parametric build - up is possible in its oscillations with frequency ω. The wave number of surface oscillations is determined by the resonance condition

$$\sigma\rho^{-1}k^3 + gk + (\mu-1)^2 H_0^2 k^2/8\pi(\mu+1)\rho = \omega^2.$$

Evaluation for the case of ML with η = 10 cP and μ = 5 with ω = 314 sec^{-1} yields that the parametric instability is possible with small intensities of the field on the order of 35 E. Experimental results confirm this evaluation. In this case, as the intensity of the variable field increases in the middle part of the flat dish with ML, a flat standing wave develops with wave front that is perpendicular to the vector of field intensity. Observations using the stroboscope indicate that the fixed structure of light lines reduces the period in half in the transition from the illumination /119 frequency 50 Hz to 100 Hz or continuous illumination. This confirms the presence of oscillations with frequency 50 Hz.

For near -threshold values of field intensity, this phenomenon is similar to the case of exciting parametric oscillations that are perpendicular to the free surface of the conducting liquid by the electrical field studied in [1]. With large field intensities, the situations differ, in contrast to the case of electrical field where the flat structure is transformed into a square, which is possible because of degeneracy of the conditions, orientation of the structure in a tangential magnetic field is linked to its direction. One should note in this case that with a sufficient increase in the field, a trend is noted in the latter for orientation at a certain angle to the direction of the field, which apparently is advantageous from an energy viewpoint.

2. In the case of fairly high frequencies of the running magnetic field, the main mechanism for exciting oscillations in the

free ML surface is parametric. Its examination can use the approximation of a uniform field rotating in a vertical plane $(0, H_0 \cos \omega t, H_0 \sin \omega t/\mu)$ (z axis of the Cartesian coordinate system is vertical, the y axis is in the direction of the spread of the running field).

Analysis of the equations for surface shifts shows that perturbations with wave front transverse to the direction of propagation will develop as a consequence of parametric instability with $H_o > H_{c1}$, where $H_{c1}^2 = 32\pi\eta\omega\mu/(\mu-1)^2$. The perturbations in the free surface with wave front along the direction of propagation of the running wave can develop as a result of instabilities of a double order: 1) static with $H_o > H_{c2}$, where $H_{c2}^2 = 16\pi\sqrt{\sigma\rho g}\,\mu(\mu+1)/(\mu-1)^2$ 2) parametric with $H_o > H_{c3}$, where $H_{c3}^2 = (\mu+1)H_{c1}^2$.

The wavelength of the oscillating structure $2\pi/k^*$ is determined by the resonance condition $\sigma\rho^{-1}k_*^3 + gk_* + (\mu-1)^3 H_o^2 k_*^2/8\pi\mu(\mu+1)\rho = \omega^2$, and the wavelength of the static structure equals $\lambda_o = 2\pi\sqrt{\sigma/\rho g}$.

Evaluation with σ = 30 erg/cm^2, μ = 5, η = 10 cP and ω = 314 sec^{-1} yields $H_{c2}/H_{c1} = 4$, from which it follows that as the field increases oscillating perturbations primarily develop with wave front transverse to the direction of propagation of the running field.

The experimentally examined situation is realized with the /120
help of a one-sided inductor powered by 50 Hz current. As the field increases , at first in accordance with the evaluation, a standing wave develops with front transverse to the direction of propagation of the running field; further a standing wave of much greater amplitude develops transverse to the first. Observations using a stroboscope indicate that in the first wave, oscillations occur with 50 Hz frequency. The spatial period of the static structure in this case is more oscillating which agrees with the evaluations with the aforementioned parameter values, which yield λ_o = 10.8 mm and $2\pi/k_*$ = 4.7 mm respectively.

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S3.16. Waves on the Surface of a Viscoelastic Liquid When There is Heat and Mass Exchange in a Weak Force Field

O. R. Dornyak (Voronezh)

Development of life support systems and power units for space vehicles makes it necessary to solve a number of problems of heat and mass exchange where there are no mass forces [1]. One of these problems is to describe the dynamics of interfaces and interphase heat and mass transfer. A number of publications cover the study of wave processes on the liquid - vapor interface; we will note [2] here.

As is known [3], the problem of waves on the flat interface of two ideal incompressible liquids in the gravitational force field results in a dispersion ratio:

$$\omega^2 = \left[gk(\rho^{(1)}-\rho^{(2)})+\sigma k^3\right]/(\rho^{(1)}\mathrm{cth}\,kh_1+\rho^{(2)}\mathrm{cth}\,kh_2), \tag{1}$$

where ω--frequency, k--wave number, g--acceleration of the gravitational force, σ--coefficient of surface tension, $\rho^{(2)}$--density of liquid layer of thickness h_2 which is on the surface of another layer of liquid of thickness h_1 and density $\rho^{(1)}$.

Publication [2] has obtained a generalization of equation (1) for the case of an ideal liquid - vapor system when there is a temperature gradient with regard for the phase transitions on the interface. This work, using a method similar to [2] studies the stability of the interphase boundry of polymer solution - vapor with regard for viscoelastic properties of the liquid and processes of heat and mass transfer under reduced gravitation conditions.

An examination is made of the layer of viscoelastic liquid of thickness h_1 which comes into contact with the vapor layer of

thickness h_2. In the equilibrium condition, the liquid has a linear temperature gradient. The temperature field in the vapor phase is uniform. It is assumed that the transition from the liquid into the vapor phase is possible only for a low - molecular solvent. The transfer processes in the liquid and vapor phases are described by mass preservation equations, the quantity of movement and energy. The Boltzmann - Volterra equation is adopted as the rheological equation of the polymer solution

$$S_{ij} = \int_{-\infty}^{t} G_1(t-\tau) e_{ij}(\tau) d\tau + \eta_s e_{ij},$$

where S_{ij} and e_{ij}--tensor deviators of stresses and rates of deformations respectively, G--relaxation function, η_s--shift viscosity of solvent. Solutions to these equations for a flat monochromatic wave on the interface after substitution into the boundary conditions yield a system of linear algebraic equations, from which the dispersion ratio for finding the frequency ω follows. The rates of propagation and damping of the wave surfaces are defined as a result of numerical solution to the found dispersion equation. A case was studied of small Bo numbers which characterize the ratio of the gravitational and surface tension forces. An examination was made of the effect of viscoelastic characteristics of the polymer solution, equilibrium temperature gradient and thermophysical properties of the liquid on the behavior of the wave on the interface surface. It was indicated that the relaxation properties of the liquid result in a weakening of damping in the surface waves in weak force fields.

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S3.17. Experimental Analysis of the Composition of a Gas and Liquid Mixture When Flowing from a Container in Weightlessness and Weak Force Fields

E. L. Kalyazin, A. G. Mednov and N. I. Shuvanov (Moscow)

An experimental study was made of nonstationary processes occurring in containers partially filled with liquid in variable force fields: overflow of the liquid into the containers from the initial inherent to the weightlessness conditions, position to the overflow opening under the influence of weak accelerations; the accompanying breakup of the gas cushion and gasification of the liquid; quieting of oscillations in the newly formed free surface; separation of gas bubbles in a weak force field; movement of the gaseous and liquid phases into containers governed by outflow.

Studies were made using methods of physical modeling of the processes in small - scale models of spherical and cylindrical shape on ground experimental test stands and units operating on board the flying laboratory. The modeling maintained similarity for the Froude numbers Fr, Weber We or Bond Bo numbers. Situations that are unfavorable for feeding liquid into the overflow line and indicated in figure 1 were adopted as the initial conditions that precede the effect of acceleration and outflow.

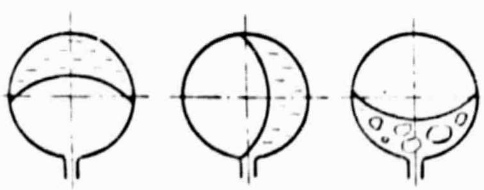

Figure 1.

The liquid in the region of the diversion device was oriented /123
using weak force fields.

During the experiments, the properties of the liquid, coefficients of container filling η, intensity of the weak accelerations a and the time of their effect τ before consumption of the gas and liquid mixture, amount of flow q and duration of outflow t were varied.

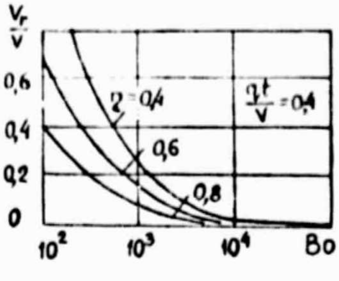

Figure 2.

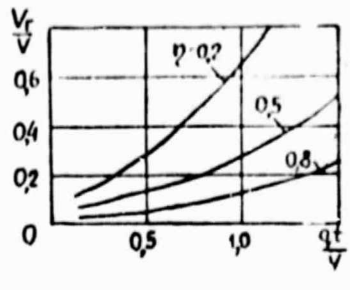

Figure 3.

The measurement systems made it possible to determine the integral volumetric ratio for gaseous and liquid phases Vr/V during overflow time t and momentary value of gas content in the model overflow line.

The experimental results were used to construct dependences of relative gas content Vg/V in the flow line of the spherical container on the Bond number $Bo = \rho a R^2/\sigma$ (see fig. 2) and on the dimensionless flow parameter qt/V (see figure 3). Here the following are designated: Vg, V--integral values for volumes of gaseous and liquid phases respectively obtained in the measured container during overflow time t; ρ and σ--density and surface tension coefficient of the liquid; R--container radius.

Experiments with outflow in a weak force field indicated that the increased gas content develops during penetration of the gas cushion into the line because of deformation or oscillations /124
in the free surface, while during outflow of the pregasified liquid, the Vg/V ratio does not exceed 0.2 even with small filling coefficients η. The experiments established that integral gas content in the line during outflow in weightlessness is considerably

greater than during overflow in a weak force field, and can change in the 0.2 - 4 range.

The experimental results were used to design gas and liquid systems of flight vehicles. Recommendations were made for selecting their operating modes and design features of the containers.

S3.18. Reaction of Liquid in an Axisymmetrical Tank to Pulse Excitation in Gravitational Fields of Varying Intensity

S. K. Nikitin (Kiev)

A numerical method is examined for studying the transient motion of a liquid partially filling a hollow rotation body, and the effect of gravitational field intensity and external pressure pulse on wave formation of a liquid in spherical and toroidal vessels. A feature of the proposed approach is the convenience of computing conditions on boundary surfaces of varying configuration and economical procedure for determining the pressure field, permitting effective realization of the algorithm for solving the problem on a computer.

A Cartesian coordinate system X, Y, Z, as well as a curvilinear coordinate system x^1, x^2, x^3 are introduced into the cavity of the tank partially filled with incompressible uniform liquid so that the boundary of the region consists of pieces of coordinate surfaces. Movement of the liquid in the coordinate system x^1, x^2, x^3 is described by Navier - Stokes equations and discontinuity equations [1], as well as the corresponding boundary conditions [3]. The equations for pressure that were obtained from the condition of solenoidality of the velocity field, jointly with the boundary conditions are a two - point boundary value problem.

Quantization of the motion equations and boundary conditions is done by the method of finite differences. The cells of the differential grid are tretragonal elements arranged in the liquid and moving together with it. The components of the velocity

vector and the metric tensor are defined in the grid centers, and the pressure, in the center of the cells. The motion equations are integrated using the Lax method in combination with explicit differential plan of the first order of accuracy. In order to determine the pressure field, at each step in time the boundary value problem is solved by the method of invariant submersion whose use makes it possible to spend considerably less machine time and computer memory on solving the problem as compared to other numerical methods [3]. Large movements in the grid region centers make it necessary to convert the metric tensor components. Therefore after determining the fields of pressure and velocity, projections are computed for the velocity vector into Cartesian coordinate axes, and new values are found for the coordinates of the grid centers and metric tensor components.

The presented algorithm was used to analyze the behavior of the liquid in a spherical and toroidal tank under the influence of the cosinusoidal pressure pulse of the medium above the free surface with varying intensity of the gravitational fields.

The fields of velocities, pressures and movements of the grid centers during the assigned time interval under conditions of gravitational fields with intensity 9.81 m/sec^2 and 0.981 m/sec^2 were found for the spherical tank. The duration of the pulse in which the liquid is separated from the tank walls and the wave crest is overturned was defined. This results in the appearance of bubbles in the region close to the free surface. It was indicated that overturning the wave occurs in the second case under the influence of a pulse load that is considerably lower than the duration. Similar calculations were made for the toroidal tank.

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S3.19. Effect of Capillarity on Dynamics of Mobile Tank Partially Filled with Liquid /126

O. S. Limarchenko (Kiev)

Work to study the dynamics of a capillary liquid partially filling a tank examined the movement of a liquid in a fixed tank or in a tank moving in advance of the assigned law, without studying the force interaction of the capillary liquid and the tank walls. This work examined the problem of joint movement of the capillary liquid and forwardly moving cylindrical tank under the influence of the pulse force load applied to the tank walls. Study of the problem of joint movement with study of the force interaction between the body and the liquid revealed new nonlinear effects that are really observed in the system.

The study was made based on methods of publications [1] and [2] based on numerical realization of Hamilton -Ostrogradskiy variational principles and minimum potential energy by direct methods of Kantorovich and Ritz.

The proposed method permits switching from the discrete - continual system structure of solid state - capillary liquid to its discrete model. The obtained system of common differential equations is linear in relation to the second derivatives and can be easily solved by the Runge - Cutt method. Nonuniform initial conditions are determined by the method of publication [2].

The obtained system of nonlinear common differential equations with nonuniform initial conditions was solved numerically for the case of a channel with rectangular cross section when its movement is excited in a horizontal direction by a square - wave force pulse. The following were adopted for the numerical calculations: $S_1 = 0.4H\ cm^{-1}$, $g = 10^{-3}g_o$, $M_z \times M_\rho^{-1} = 5$, $z = H = 0.1$ m, $\tau = 1$ sec, $g_o = 9.81\ m \times sec^{-2}$, $\theta = \pi/3$, σ and ρ were taken for

water (here all the designations of publication [1] were adopted).

In addition to the known effect of "smoothing " the wave profiles by means of the surface tension forces, it was established that the magnitude of the main vector of the liquid pressure forces R on the side walls of the tank with unaltered geometric dimensions /127 of the tank, level of filling it and ratio of the tank and liquid masses depends on the initial perturbations in the free surface of the liquid and on the external force f. In particular, for the case where initial conditions are uniform (as in the case of $g = g_0$, also in the case of $g \ll g_0$) in a broad range of change in the external force R = 0.428 f. In the case of $\dot{\theta} = \pi/3, g = 10^{-3} g_0$ the nature of the relationship changes, although the linear law for the dependence of the change in the response on the external force is disrupted in a broad range: R = 0.325 f.

The obtained effect of the dependence of the coefficient of proportionality between the magnitudes of the main vector of liquid pressure forces on the tank wall and external force on the initial perturbations of the free liquid surface is a consequence of the manifestation of nonlinear bonds in the system. The linear theory does not reflect this dependence. In the proposed model, this effect is a result of the fact that the excitation at the initial moment in time of certain forms caused by capillarity results in a different manifestation of nonlinear bonds in the system, and in the final analysis, this governs the quantitative discrepancies. The obtained result can be viewed as a behavioral feature of the body and liquid systems under conditions where the effect of the surface tension forces is significantly manifest.

Thus, the main behavioral features of the tank -capillary liquid system are manifest in studying the forces of interaction between the liquid and the tank walls, and they consist of the dependence of the main vector of the liquid pressure forces on the tank walls on the initial condition of the liquid which is

determined to a considerable measure by the capillary properties of the liquid.

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S3.20. Ground Modeling of Capillary Effects Developing in Small - Celled Grids in Liquid in Weightlessness /128

L. G. Aleksandrov, S. S. Zakharov and A. A. Kozlov (Moscow)

S3.21. Effect of Rotation on Nature of Movement and Shape of Liquid Masses in Reduced Gravitation

V. Ya. Rivkind (Leningrad)

An examination is made of the movement of closed volumes of liquid masses in a viscous incompressible liquid. In this case, two possible situations are studied: forward movement of the drops in a uniformly rotating medium and uniform rotation in a forward moving drop in a fixed medium. In both cases, during movement, the effect of the gravitational forces with different magnitude of acceleration of the gravitational force is taken into consideration. A study is made depending on the ratio between the Taylor, Reynolds, Weber and Bond numbers of the structure of flow of a liquid mass and outside of it. Features are noted which are caused by rotation (increase in the zone of the age flow) with the appearance of vortexes in any part of the flow.

S3.22. Equilibrium and Motion of a Drop in a Porous Medium

A. F. Glukhov and G. F. Putin (Perm')

One of the methods for modeling weightlessness and weak gravitation in studying the equilibrium configurations and drop stability consists of submerging it into the liquid of the same or close density. The free drop in weightlessness is contracted into a sphere which has the minimum surface energy. The weak mass

forces put it into motion with constant rate proportional to the difference in densities $\Delta\rho$ and square of the radius. The small perturbations in the surface are damped in both cases. /129

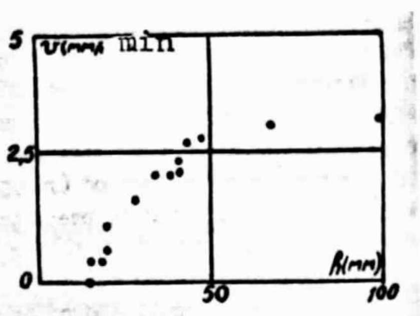
In the proposed work, a similar examination is made for a drop placed in a porous medium. The porous material is crushed glass separated into fractions from 0.3 to 1.5 mm. The permeability of the media is 10^{-7} - 10^{-5} cm^2, porosity is 0.3. For visual purposes the powder was saturated with a solution of bromobenzene in hexane that has the same refraction index as the glass. Globules from several millimeters to tens of centimeters which both wet the medium in the presence of a solution (water, different acids) and do not wet it (air, mercury, solution vapors) were studied. For comparison, soluble drops were studied where the surface forces are inactive.

In the force field, the drops without surface tension acquire constant velocity proportional to the moving force and permeability of the medium, but do not depend on the radius, since friction acts in their entire volume. The forefront of the moving drops is unstable, and it is broken down into two - three "fingers" on the path of several diameters. These "fingers" grow by the exponential law for an unexpectedly long time, all the way to amplitudes comparable to the drop size, as in the flat front calculations [1].

In order to move the interface on the capillary formed by the connecting pores, it is necessary to exceed the threshold pressure determined by heterogeneity in pore dimensions and meniscus curvature. Therefore in weightlessness, when there are capillary effects, any drop configurations in the porous medium are equilibrium. The drop becomes quiet because of capillary closures even with significant disruption in the balance of gravitational and Archimedes' forces. Manometric measurements and experiments in centrifugal fields established that the dimensionless criterion which determines the equilibrium conditions

for a globule of random shape is the ratio $\Delta\rho gh/p$ of the hydrostatic differential to the sum of threshold pressures on its upper and lower boundaries (g--acceleration of the gravitational force, h--height of the drop). The drop is put into motion when $\Delta\rho gh/p \geq 1$. With assigned g and $\Delta\rho$ there is a critical height h_k whose exceeding disrupts the equilibrium. Thus, for water ($\Delta\rho$ = 0.3 g/cm^3) in a medium made of particles 0.3 mm in size, h_k = 15 cm.

A study was made of the dynamics of a wetting drop of super-critical dimensions. Since the threshold pressure of this drop /130
on the approach front is lower than on the retreating, its rear boundary lags, and the drop is pulled into a stream by a section one - third of the initial, experiencing chaotic deviations from the vertical because of microheterogeneities in the medium. The velocity of the front boundary of the drops whose height is close to h_k rises rapidly with an increase in $h - h_k$. Therefore, at the initial stage, elongation of these drops is accompanied by their acceleration. When advance of the forefront is compensated for by the corresponding retreat of the rear saturation boundary because of a loss in the form of the adsorbed film and small drops, a stationary settling mode is set. At the final stage, the height of the saturated globule diminishes to the critical, and its velocity drops to zero. The increase in g again disrupts the equilibrium, and the process is repeated. If $h \gg h_k$, the capillary forces are small as compared to the mass, and since the saturated globule is great, the stream spreads with constant velocity that does not depend on h. The duration of the stationary settling is proportional to the initial volume. The dependence of the stationary velocity v on the height of the drops of sulfuric acid in a medium made of particles 0.5 - 1.0 mm is shown in the figure.



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S3.23. Drop Dynamics in a Porous Medium in a Vibration Field

N. A. Bezdenezhnykh, A. F. Glukhov, S. V. Zorin, V. I. Noskov, G. F. Putin, G. F. Shaydurov (Perm')

Addition to the static gravitational field $\vec{g}$ of an oscillating component can significantly influence the equibrium of the configuration and the dynamics of the drop that is submerged in another liquid [1]. This work experimentally studies the effect of vibrations on a drop that is in a nondeformable permeable medium consisting of glass grains 1 - 1.5 mm in size; its porosity is 0.2, the coefficient of permeability is 10^{-6} cm^2; the drop diameter is ten and more times greater than the pore dimensions. An immersion method of visualization is used. The vèssel filled with medium is 6 cm in diameter and 20 cm high. It is oscillated at a random fixed angle to $\vec{g}$ by electrodynamic vibration stand that developed at resonance frequency 70 sec^{-1} an amplitude to 0.9 mm which corresponds to g-forces up to 18 $\vec{g}$.

In the absence of capillary effects, the velocity and evolution of a drop on the interface in the static force field and with the application of the indicated vibrations are the same. The qualitative behavior of the drop with surface forces (studies were made on drops of water, sulfuric acid and air) in the oscillating field also did not change: regardless of the direction of vibrations, the drops whose height is less than the critical h_k are in equilibrium, and the large are shifted towards the equivalent force of the Archimedes' and gravitational forces, breaking down during movement into parts which are halted when their size diminishes to h_k. However the threshold value h_k with an increase in the vibration amplitude to the maximum diminishes by an order. This significantly increases the path traversed by the drops until halting, and the settling rate of the small drops. Vibrations are thus an effective means of separating the immiscible liquids in a porous medium.

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S3.24. Numerical Solution to the Problem of Drop Spread on a Plane with Change in the Gravitational Field /132

V. K. Polevikov and I. V. Nikiforov (Minsk)

A numerical study was made of the change in time in the shape of an axisymmetrical drop falling on a horizontal plane under the influence of the gravitational force. The following system of equations was examined in this case:

$$\frac{\partial u}{\partial t} + u\frac{\partial u}{\partial r} + v\frac{\partial u}{\partial z} = -\frac{1}{\rho_0}\frac{\partial p}{\partial r} + \nu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial u}{\partial r}\right) + \frac{\partial^2 u}{\partial z^2} - \frac{u}{r^2}\right],$$

$$\frac{\partial v}{\partial t} + u\frac{\partial v}{\partial r} + v\frac{\partial v}{\partial z} = -\frac{1}{\rho_0}\frac{\partial p}{\partial z} + \nu\left[\frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial v}{\partial r}\right) + \frac{\partial^2 v}{\partial z^2}\right] - g,$$

$$0 = \frac{1}{r}\frac{\partial}{\partial r}\left(r\frac{\partial p}{\partial r}\right) + \frac{\partial^2 p}{\partial z^2} + \rho_0\left[\left(\frac{\partial u}{\partial r}\right)^2 + \left(\frac{\partial v}{\partial z}\right)^2 + \left(\frac{u}{r}\right)^2 + 2\frac{\partial u}{\partial z}\cdot\frac{\partial v}{\partial r}\right],$$

where velocity components u, v and pressure p are unknown. We note that the formulated problem is equivalent to the problem of behavior in weightlessness of magnetic fluid drops that have reached a plane where the role of the gravitational force is played by a force of interaction between the liquid and the external magnetic field that has a constant intensity gradient. The problem was solved by the modified method of markers and cells. The boundary conditions for pressure on the free surface were assigned according to the Laplace law, i.e., with regard for the surface tension. An attempt was made to calculate the wetting effects; in this case, the implicit quadratic interpolation was used to describe the shape of the meniscus. Primary attention was focused on studying the effect of the gravitational field and the wetting angle on the evolution of the drop shape. The shape of the drop that was established in time was compared with the equilibrium form obtained as a result of solving the axisymmetrical task regarding drop

equilibrium on the plane. The surface equilibrium equation [1] was solved by the shooting method.

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S3.25. Control of Electrorheological Liquid Flow

A. T. Listrov (Voronezh)

When a dielectric suspension flows in an electrical field, its effective viscosity changes [1].

An examination is made of the low - concentration suspension of the same spherical dielectric particles in a weakly conducting liquid. In a uniform constant electrical field, each solid particle of this suspension under definite conditions is put into spontaneous constant rotation around the axis that lies in the plane, orthogonal to the vector of electrical field intensity [2]. The arrangement of the axis and the sign of angular velocity of rotation of each particle depends on the random initial conditions. It has been indicated that orientation and the magnitude of the angular rotation velocity vector of each particle can be controlled by forming in time in the suspension a uniform stationary shear flow in a definite manner. The presence of spontaneous particle rotation results in asymmetry of the stress tensor and change in the effective viscosity of the suspension. It has been found that the uniform constant electrical field can reduce the effective viscosity of the suspension, and also create secondary flows on the background of a one - dimensional shear flow.

The technical use of dielectric suspensions whose solid phase is magnetic particles in dielectric shells is promising. These magnetic electrorheological suspensions in combined hydrodynamic and electromagnetic fields display not only electrorheological and magnetorheological effects, but also specific properties that are governed by cross phenomena.

An examination was made of different flows of low - concentrated magnetic electrorheological suspensions in electrical and magnetic fields. Formulas were obtained for effective viscosity of suspensions with one - dimensional stationary shear flows which generalize the results of G. Brenner [3]. /134

The possibility is shown of controlling the electrorheological effect by external magnetic field. Deformation and interaction of the diffuse shells that cover the double electrical layers surrounding the suspension particles were not taken into consideration.

The particles do not have a constant electrical dipole moment.

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S3.26. Numerical Modeling of Viscous Liquid Flow in a Channel with Deforming Walls

G. V. Levina (Perm')

Peristaltic transportation of a liquid is widely used in technical devices. An analytical study was made of peristaltic flows for small parameter values [1]. The numerical approach makes it possible to compute the finite - amplitude pumping with random values of the Reynolds number and wave number.

An examination was made of the motion of a viscous incompressible liquid in a flat infinite channel when there is no gravitational force caused by the change with time by the harmonic law in the shape of the channel boundaries. Deformation of the walls is assigned in

the form of a running wave that spreads at a rate of c:

$$h(x,t) = b \cdot \sin \frac{2\pi}{\lambda} (x - ct),$$

where b--amplitude, λ--wavelength. /135

A study was made of the mode of peristaltic pumping by the method of finite differences with the following values for dimensionless parameters: relative amplitude ε = 0.1 - 0.9, wave number α = 0.1 - 1.5, Reynolds number Re = 0 - 3000.

The problem was solved in variables of the current function ψ and velocity vortex ϕ. Using coordinate transform, a transition was made to the rectangular system of coordinates moving together with the wave.

With small values of the parameters ε, α and Re, a good agreement was obtained between the results and the available analytical solutions [2]. Dependences were found for the integral characteristics of pumping on the problem parameters. Flow patterns were obtained and boundaries were defined for the existence of "reverse current" and "closure" effects for the finite values of parameters.

The principle of pumping a liquid that was examined in the work can be used to create devices that are active in weightlessness.

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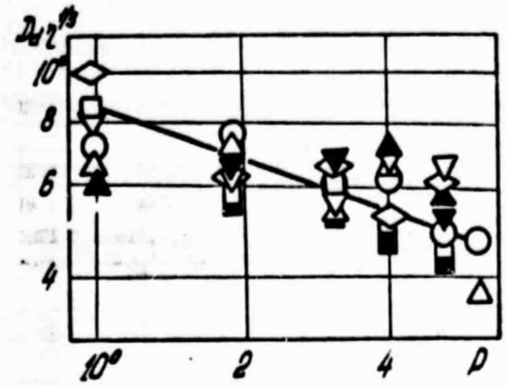
SECTION 4. HEAT AND MASS EXCHANGE IN MULTIPHASE MEDIA AND RELATED QUESTIONS /136

4.1. Some Microcharacteristics of Oxygen Bubble Boiling with Weakened Gravitation

Yu. A. Kirichenko and G. M. Gladchenko (Khar'kov)



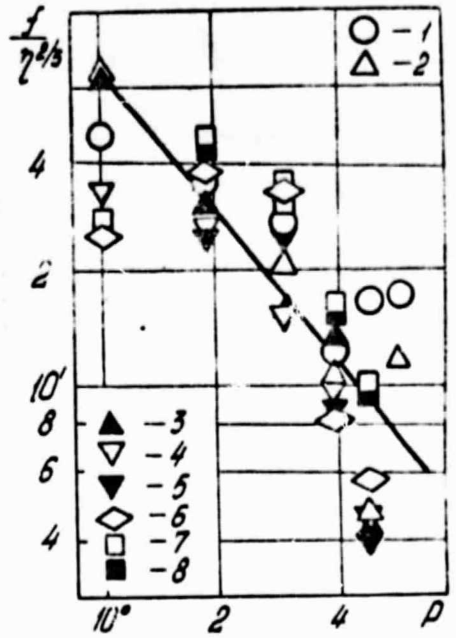
An experimental study was made of the joint effect on dynamics of vapor bubbles of acceleration ($\eta = g/g_n = 0.02 - 1$) and pressure ($p = 1 - 6$ bar) when oxygen is boiled on a single center. The weak mass force fields were simulated using a nonuniform magnetic field [1].

In the studied range p and η, the growth of bubbles is satisfactorily approximated by the expression $R = \beta\tau^n$ with $n = 0.45$; the growth module of β does not depend on the acceleration and is determined by the Jacobi number $Ja = \lambda\,\Delta T/(L\rho' a)$.

It was found that with any value of p, the separation diameter of the bubble D_d changes as $D_d \sim \eta^{-0.3}$. Figure 1 shows that the joint effect of p and η on D_d in the studied range of variables is satisfactorily described by the expression $D_d = 0.8\,\eta^{-1/3} p^{-0.36}$ (p in bar; D_d in mm).

The magnitudes of the indicators are close to the theoretical which is characteristic for the quasistatic separation mode [2].

According to experimental data, the separation frequency $f \sim \eta^{0.62}$. With constant acceleration, f is reduced with a rise in /137
pressure as indicated in figure 2. Here 1 - 8 respectively η = 1, 0.5, 0.3, 0.2, 0.1, 0.05, 0.03, 0.02. The dependence of f on p and η can be generalized by the expression $f = 60\eta^{2/3}p^{-1.1}$.



The findings indicate that in the studied range of pressures and g-forces, their effect on the boiling microcharacteristics can be considered independent, while the quantities D_d and f can be defined from the known theoretical formulas.

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4.2. Oscillating Phenomena in Multiphase Systems and Their Use in Space Technology

R. F. Ganiyev (Moscow)

4.3. Coagulation and Sedimentation of Components in Liquid Metal Systems in Weightlessness /138

Yu. M. Gel'fgat and S. I. Semin (Riga)

Publications [1, 2] have studied the possibility of obtaining in weightlessness alloys of the "frozen emulsion" type, Zn - Pb, Al - Pb. Experiments in quasiweightlessness where neutral equilibrium of the components was realized through purposeful electromagnetic effect on the binary liquid - metal melt have a similar goal [3, 4]. Negative results that were recorded in the space experiments and in a number of experiments in quasiweightlessness make it necessary to analyze the breakdown of similar media with regard for all the factors that are capable of influencing the kinetics of the process. This work covers this problem.

By using the model for breakdown of binary liquid and metal systems suggested in [5] with area of immiscibility, the following main factors influencing the process in weightlessness were defined. This, first of all, is the presence of residual accelerations and convective movement of the molten metal, and in quasiweightlessness, in addition, the interaction of the electrical current with the natural magnetic field.

In order to evaluate the effect of each of the listed factors, an examination was made of the kinetic coagulation equation [6]. In this case, in addition to the Brown coagulation, collisions were taken into consideration which the particles of the dispersed phase undergo during directed motion caused by the effect of each of the indicated factors. For example, the presence of residual accelerations results in the development of gravitational coagulation and sedimentation, and so forth. Specifically, numerical methods were used to solve a system of equations that was compiled for moments of zero and first order in relation to the unknown function for distribution of particles by volume [6]. By varying the different input parameters of the problem, the integral characteristics for the process were successfully generalized by the following relationships

$$t_r^* = \frac{(2\cdot 10^3 - 1/a)\rho\nu T^{0.75}}{W_0[\varkappa\lambda(\rho_p-\rho)]^{0.75}}, \qquad t_\kappa^* = \frac{5\cdot 10^3 a^{0.71}\rho\nu T^{0.75}}{W_0[u_0^2\lambda(\rho_p-\rho)]^{0.75}},$$

$$t_э^* = \frac{3\cdot 10^8 \rho\nu}{W_0 a^{0.64}}\left(\frac{2\sigma+\sigma_p}{|\sigma-\sigma_p|}\cdot\frac{T}{j_0^2\lambda}\right)^{0.74}, \qquad \lambda = \frac{1+\nu/\nu_p}{1+2\nu/3\nu_p},$$

where t^*--time needed for the system for 10% of the dispersed phase to pass into large - scale inclusions; the index "r" characterizes the breakdown through residual accelerations, "k" characterizes the convective motion of the melt, "e" characterizes the interaction of the electrical current with natural magnetic field; --the level of residual accelerations, and in the case of quasiweightlessness, accurate compensation for the difference in phase densities; j_0--

density of electrical current; u_o--characteristic velocity of convective motion; a--characteristic size of container; ρ, ν--density and kinematic viscosity;   --temperature; index "p" refers to the dispersed phase; W_o--initial concentration of dispersed phase.

The results of the conducted analysis were compared with the experimental data obtained in quasiweightlessness [4], and were completely confirmed in a qualitative respect. This provides the grounds to recommend the findings to evaluate the characteristic parameters of conducting the process both in modeling and directly in space experiments on crystallization of liquid and metal systems with area of immiscibility.

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4.4. Evaluation of Outlook for Different Methods of Electrophoresis for Space Biotechnology /140

V. G. Babskiy, M. Yu. Zhukov and V. I. Yudovich (Kiev, Rostov-na-Donu)

Electrophoresis of cells, proteins, nucleic acids and biological active substances is one of the main trends for space biotechnology. However, with the extant diversity in the electrophoresis methods by objects, principle of separation (for mobility or isoelectrical points), type of supporting media or stabilizing

gradients of density, configuration of electrophoretic chambers, methods of indication and recording of the process, etc., a natural question is raised of which criteria one should be guided by in selecting certain ground variants of electrophoresis for space technology.

Based on theoretical studies of the authors [1] and analysis of experimental data, this report discusses the following system of criteria:

1. "Coefficient of use" of weightlessness conditions. Electrophoresis under conditions close to weightlessness has potential advantages because of the reduced danger that gravitational convection will develop, and the greatest advantages are found, generally speaking, in those methods of electrophoresis in which the greatest temperature and density gradients develop. This is primarily isotachophoresis and isoelectrofocusing of proteins where the electrophoretic separation of objects occurs in the form of narrow concentrated zones.

2. Need for supporting media. The supporting media, in particular, gels, in addition to anticonvection action can have a direct influence on electrophoretic separation; thus, apparently, free liquid electrophoresis of high molecular DNA is not successfully performed. The question of abandoning or using the supporting media requires careful analysis; one should take into consideration that the gels can undergo changes under the influence of space flight factors (experimental results are given).

3. Level of mathematical modeling. A theory of zonal electrophoresis, isotachophoresis, isoelectrofocusing in finite and infinite component systems has currently been drawn up. This theory in principle permits computation of the process dynamics in terms of concentrations of substances, intensity of the electrical field and heat emissions, recommendations on the best organization

of the process, as well as extrapolation to those conditions under which the liquid electrophoresis is unfeasible on Earth with the known parameters of the buffer systems and separated substances and electrophoretic mode.

4. Recording method. An analysis is made of the reliability and information content in photography, spectrometry, thermometry and return of samples from the viewpoint of comparing results of flight experiments with theoretically predicted results.

5. Energy consumption, dimensional and weight restrictions.

6. Supply with chemical reagents. In the example of isoelectrofocusing, an analysis is made of the possibility and outlook for use of domestic developments and chemical reagents.

7. Importance of the object, its degree of study, requirements for storage and conditions of conducting electrophoresis. The most important biotechnological problems for separation and purification of the producer cells of biologically active substances are analyzed; enzymes and antiobiotics; nucleic acids and their restrictions. The need is indicated for determining the physical - chemical and thermophysical characteristics of the main objects for electrophoretic separation.

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S4.1. Questions of Formation and Growth of a Single Bubble on a Solid Surface in a Field of Mass Forces of Different Intensity /142

Yu. A. Kirichenko and N. S. Shcherbakova (Khar'kov)

Numerical solution to the problem of stable equilibrium of axisymmetrical bubbles growing on the edge of a hole made it possible to obtain results that could be used for boiling on a microdepression

and bubbling through different radius holes in a broad range of g-forces $n = g/g_n$ in a quasistatic mode.

The size of the active microdepression on the heater surface was evaluated based on data regarding the dependence of the pressure differential on the volume of the growing bubble. The maximum pressure differential should determine that temperature differential between the vapor in the bubble and the surrounding liquid in which growth of the bubble to breaking dimensions is possible. The curve for the dependence of maximum pressure differential on the radius of the microdepression has the appearance of a hyperbola $\Delta p = 2.01\sigma/r_c$ in the range $r_c\sqrt{\Delta\rho\, n g/\sigma} < 0.2$ where r_c--radius of microdepression, $\Delta\rho = \rho' - \rho''$, ρ', ρ'' --densities of liquid and vapor, σ--surface tension. This fact and examination of the bubble shpaes when they reach the maximum pressure differential made it possible to obtain an evaluation of the radius for the active depression in a form similar to that previously obtained for the bubble in a volume

$$r_c = \frac{2.01\, \sigma\, T_s}{L\, \rho'\, \Delta T}\ .$$

Here T_s--saturation temperature, L--heat of vapor formation, ΔT--temperature differential. It has been indicated that the radius of the active microdepression does not depend on the intensity of the mass force field.

The behavior of the pressure differential inside the bubble with increase in its volume determines the dependence of the bubble radius time in its growth plan with constant pressure realized during bubbling.

Change in pressure differential in the bubble is characterized in this case by the pressence of two growth stages. In the first, shorter Δp_o (pressure differential at the bubble apex) increases /143
to the maximum, and then drops all the way to the separation point. The smaller the radius of the hole through which bubbling occurs,

the shorter the stage of increase in pressure differential. It was found that for the stage of decreased pressure differential, the law for change in the bubble radius on time looks like $\imath = a\tau^{b}$ where b depends on the hole radius and slightly depends on the g-force. In the range R_o = 0.5 - 0.02 (R_o--dimensionless radius of the hole defined by $R_o = \imath_o\sqrt{\Delta\rho n g/\sigma}$) b changes in the interval 0.48 - 0.37.

As a result of analyzing the dependence of the breaking radius of the bubble on pressure with calculation of the possible change in the radius of the active microdepression because of change in the physical properties, a hypothesis was advanced that in some cases the curve for the dependence of the breaking radius of the bubble on pressure characterizes the effect of pressure not only on the bubble breaking radius, but also on the radius of the active microdepression. A comparison was made of the obtained evaluation with the experimental results of other authors.

S4.2. Effect of Mass Force Field on Heat Exchange in a Closed Volume with Change in the Relative Vapor Content of a Two - Phase Medium

Yu. A. Kirichenko and Zh. A. Suprunova (Khar'kov)

A technique was developed for computing the temperature field in a closed volume partially fillled with liquid. Generalized formulas for computing the main process characteristics were found based on results of an experimental study of heat exchange in spherical and toroidal vessels filled with normal and cryogen liquids. These characteristics include temperature of the interface T_s and time for formation of cyclic motion in the liquid volume τ_*. For the quantity ϑ_s which is an increase in time in the interface temperature ϑ_s = Ts - To, the following ratio was obtained

$$\frac{\vartheta_s c_p}{L} = 0.65\, H_{o*}^{0.78}\left(\frac{\tau}{\tau_*}\right)^{n}\left(\frac{1-m}{m}\right)^{-0.30}. \qquad (1)$$

In (1), $H_{o*} = q\tau/(m\ell\rho L) = 1.2\ 10^{-3} \div 7.8\ 10^{-2}$; $m = V_*/V = 0.20 \div 0.93$, $\ell = \imath/3, \imath/2$, for a sphere and tore respectively. /144

The time $\tau*$ is described by the ratio

$$\frac{a\tau_*}{\ell^2} = 6.12\cdot 10^{5}\,\mathcal{R}a^{-0.41}\,Pe^{-1.66}\left(\frac{S_г S_ж}{S^2}\right)^{3.6}. \qquad (2)$$

In (2) $\mathcal{R}a_\ell = 2.5\cdot 10^8 \div 4.3\cdot 10^{10}$; $Pe = 1.6 \div 45.0$; $S_г S_ж / S^2 = 0.69 \div 1.96$; $S_г, S_ж$ is the surface of the vessel which is washed by gas and liquid respectively.

Expression (1) with regard for (2) for specific values of the index n presented in figure 1 in the form of the relationship $n = f(1-m/m, \rho''/\rho')$ can be transformed to an appearance which corresponds to specific values of the quantities ρ''/ρ' and $(1-m)/m$. Thus, for hydrogen ($\rho''/\rho' = 1.7 \times 10^{-2}$), the value n = 0.54 corresponds to the value (1 - m)/m = 1, in which the expression (1) is transformed into the appearance

$$\frac{\vartheta_s \lambda}{q\ell} = 12.1\left(\frac{q\ell c_p}{\lambda L}\right)^{-0.24}\left[m^{1.5}(1-m)\right]^{-0.3} Fo^{0.54}\,\mathcal{R}a^{-0.09}\,Pe^{-0.36}\left(\frac{S_г S_ж}{S^2}\right)^{0.79}. \qquad (3)$$

For water ($\rho''/\rho' = 10^{-4}$), the index n = 1.05 corresponds to the quantity (1 - m)/m = 1 for which expression (1) is transformed into the appearance

$$\frac{\vartheta_s \lambda}{q\ell} = 0.02\left(\frac{q\ell c_p}{\lambda L}\right)^{-0.24}\left[m^{1.5}(1-m)\right]^{-0.3} Fo^{1.05}\,\mathcal{R}a^{0.12}\,Pe^{0.46}\left(\frac{S_г S_ж}{S^2}\right)^{-1}. \qquad (4)$$

In (1) - (4), L, c_p, λ, ρ, q--heat of vapor formation, heat capacitance, heat conductivity, density of the substance, density of the heat flow on the vessel surface.

Formulas (3) and (4) and data of figure 1 make it possible to draw the following conclusions.

1. The values of the coefficients and the exponents in (3) and (4) change with a change in the quantity n. This means that the degree of influence from individual effects that can be described by the corresponding similarity numbers changes with a change in the vapor content of the two-phase system $x = (1 - m)\rho''/(m\rho')$. What

has been said refers to the effects associated with the influence of the mass force field (Rayleigh criterion).

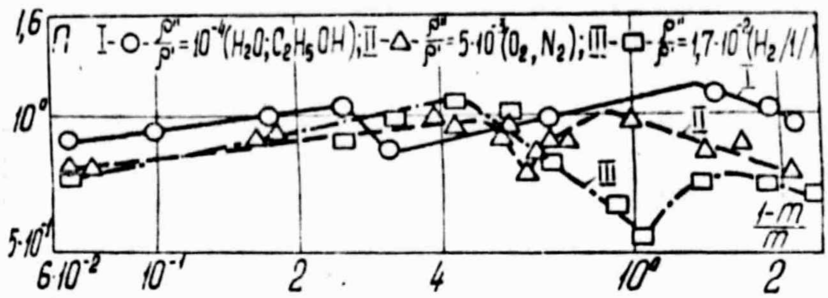

Figure 1. /145

2. A definite type of expression of type (3) and (4) which can be defined from formulas (1) and (2) and data of figure 1 corresponds to each liquid with the corresponding values ρ''/ρ' and $(1 - m)/m$.

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S4.3. Overheating and Explosive Boiling of Cryogen Liquids

V. P. Skripov, V. G. Baydakov, A. M. Kaverin and S. A. Malytsev (Sverdlovsk)

During storage, transporting and use, cryogen liquids are in a state of boiling or close to it. Therefore the local heat flows, pressure pulsations caused by operating conditions can result in local overheating of the liquid. Removal of the non-equilibrium is accompanied by hydraulic shocks and has an explosive nature when there is great depth of penetration into the metastable region.

This work presents results of experimental studies on the kinetics of fluctuation boiling and attainable overheating of a /146

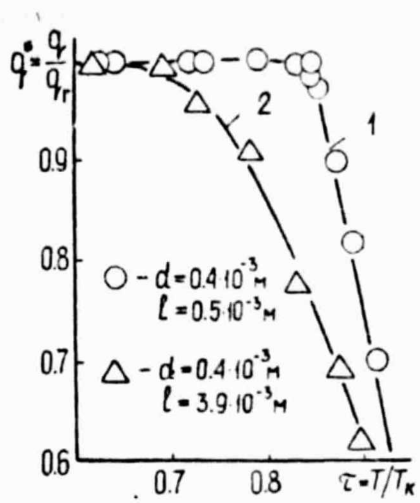
number of cryogen liquids under static conditions and with outflow into the environment. The temperatures of attainable overheating Ar, N_2, O_2, CH_4, Ne, H_2 were measured in the pressure interval from close to atmospheric to about 0.7 p_k, where p_k is the pressure at the critical point. A method was used of continuous isobaric heating of liquid in glass capillaries. The obtained data refer to frequencies of seed charge formation $J = 10^{11} - 10^{12}\ m^{-3}sec^{-1}$. Temperature values of the attainable overheating T_n of some of the studied substances at atmospheric pressure are presented in the table. It also indicates the normal boiling temperature Ts.

Substance	Ts, K	Tn, K
Ar	87.29	130.8
N_2	77.35	110.1
O_2	90.19	134.1
CH_4	111.66	165.9

The kinetics of boiling cryogen liquids near the boundary of attainable overheating (Ar, N_2, O_2, CH_4) was studied. The experiments defined the average lifetime of the metastable liquid with assigned p and T. The range of studied frequencies of seed charge formationis $J = 10^4 - 10^{-8}\ m^{-3}sec^{-1}$. All the obtained data refer to conditions of homogeneous seed charge formation where the seed charges of the vapor phase develop as a result of thermal fluctuations. This case is the most interesting in a theoretical respect and can be viewed as the maximum under industrial conditions. Comparison of experimental data with the theory of homogeneous seed charge formation indicated: 1. Characteristic slope of the temperature relationship lnJ, predicted by theory is close to that which is observed in experiment (Ar, $d\ln J/dT \cong 20$); 2. In theory, the order of the magnitude of transition velocity of the bubble through the critical size is correctly determined; 3. The temperatures observed in the experiment for attainable overheating are systematically (by 0.3 - 0.8 K) lower than the calculated, if in theory a "macroscopic" description was used for surface properties of the bubble ($r \cong 10^{-8}m$). This work suggests a method for computing the operation of seed charge formation that is not associated with

the macroscopic model and permits coordination of the theoretical and experimental data.

Considerable overheating is observed when the boiling cryogen liquids flow out through the short adapters. Experiments were conducted with liquid N_2 and O_2 that flows from a high pressure chamber into the atmosphere through cylindrical channels of length /147 $\ell = (0.5 - 5) \times 10^{-3}$m and diameter $d = (0.3 - 0.6) \times 10^{-3}$m. A study was made of the dependence of liquid consumption on temperature with assigned pressure in the chamber p_o. The figure shows the consumption characteristics that were obtained in experiments with oxygen with $p_o = 3.0$ MPa. Specific consumption of nonboiling liquid computed by the Bernoulli equation q_r, and the temperature of the critical point Tk were selected as parameters. Up to temperature



of about 0.86 Tk, the measured flows (curve 1) are close to the computed for the case of nonboiling liquid. In the region of $\tau > 0.86$, spontaneous seed charge formation in the flow nucleus results in a sharp change in consumption. Increase in the length of the channel (curve 2) causes a monotonic reduction in consumption with a rise in temperature. The pressures in the short channels computed from experimental data with $T > 0.86$ Tk are close to those obtained in experiments to study the attainable overheating.

S4.4. Effect of Gravitation on Kinetics of Gas Bubble Formation in a Melt

A. A. Ushkans, V. P. Shalimov (Riga, Moscow)

This work examines the question of kinetics of gas bubble formation in multicomponent melts with different degree of gravitation. The effect of hydrostatic pressure on the pressure of

saturated vapors in the seed charge, on the rate of generation and critical bubble radius was computed. Calculations were made of a number of systems confirmed for specific examples.

S4.5. Dynamics and Heat and Mass Exchange of Bubbles in Rheologically Complex Media /148

S. P. Levitskiy, Z. P. Shul'man (Voronezh, Minsk)

Study of the processes of pulse, mass and energy transfer in two - phase media is very important for a number of problems in modern space equipment and technology [1]. The key problem in the dynamics of two - phase systems is description of thermal, mass and dynamic interaction with liquid of single inclusions. Pulsations of bubbles in normal Newtonian liquids have currently been studied in detail with regard for many factors [2]. There has been considerably less study of the features of dynamics and heat and mass exchange of inclusions in the rheologically complex media, of which the most important in this respect are the polymer systems. This work studied the free oscillations in the steam and gas bubbles in a polymer solution with rheological equations [3]:

$$\tau_{ij} = 2\int_{-\infty}^{t} G_1(t-\tau) s_{ij}(\tau)\, d\tau + 2\eta_s s_{ij}, \qquad \sigma_{kk} = -3p_{20} + 3\int_{-\infty}^{t} G_2(t-\tau) e_{kk}(\tau)\, d\tau - 3\int_{-\infty}^{t} G_3(t-\tau) \frac{\partial \theta_2}{\partial \tau}\, d\tau + 3\rho_{20}\eta_v e_{kk}. \tag{1}$$

Here τ_{ij}, s_{ij}--deviators of stress tensors σ_{ij} and deformation rates e_{ij} respectively; θ_2--perturbation of temperature; ρ_{20}, P_{20}--equilibriumn density and pressure; G_1 - G_3--relaxation functions; η_s, η_v--shear and volumetric viscosities of the solvent. Damping of bubble pulsations in the medium (1) after passage of a weak pressure pulse is examined. Using the technique similar to [4], an equation was obtained for the natural frequency of bubbles of variable mass. Numerical calculations were made in the temperature range from 20°C to T_{boil} as applied to polymer solutions in easily volatile solvent (toluene) using discrete relaxation spectra of the Rose - Spriggs type. An analysis was made of the effect on

frequency and damping of bubble pulsations of a number of factors: nature of spectral distribution of the relaxation times, nonequilibrium of the phase transitions, magnitude of specific heat of evaporation of the solvent, vapor content in the bubbles , capillary effects, /149 etc. It was indicated, in particular, that calculation of the visco-elastic properties of high polymer solutions with great viscosity result in a drastic weakening in inclusion pulsation damping. This result indicates the possibility of using highly viscous polymer liquids to model the free bubble pulsations in reduced gravitation, since in these media there is a sharp reduction in the mobility of the inclusions in the gravitational force field because of the large magnitude of viscous resistance, and the dissipative losses with radial oscillations in the bubbles are much smaller than in a similar viscous liquid.

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S4.6. Elementary Theory of Gas and Liquid Systems

M. A. Gol'dshtik (Novosibirsk)

The theory of gas and liquid systems in recent years has been significantly developed, nevertheless all the main information has been obtained by experiment. This is because the theoretical works focused primary attention on examining the strongly idealized interactions in the gas and liquid mixtures and methods of averaging in the mechanics of heterogeneous systems. The continuous equations

are mainly used to study waves in an unlimited gas and liquid medium. The boundary value problems of gas and liquid hydrodynamics have not yet been raised.

This publication has undertaken a phenomenological derivation of motion equations of gas and liquid systems based on the requirement for correct description of different maximum situations. The /150 main sample object for application of the theory is the problem with gravitational bubbling which reveals a number of important properties that are difficult for theoretical explanation. This includes, for example, the following questions:

a) Why can the rate of the gas phase inthe bubbling columns be an order greater than the rate of floating of a single bubble?

b) Why is the velocity of the water drops flowing in mercury roughly an order lower than the velocity of floating of the air bubbles in water?

c) Why doesthe gas content in the bubbling layer essentially not depend on the arrangement of the gas distribution lattice?

d) Why is the gas content in the lower layers significantly greater than the high layers? According to considerations of stability, the gas content in the bubbling layer should increase in height, which is also observed in the experiment. Therefore with the same input conditions, the high layer would apparently be more gas saturated than the low. However experience provides exactly the opposite result.

e) What exactly is the crisis of forcing back and what determines it? Why doesthe criterion of forcing back not depend on height of the layer? For it would seem that it is more difficult to displace the high layer.

f) How can one explain the phenomena of ambiguity of modes and hysteresis observed in experiment?

This work, based on the general statement of the problem of gas and liquid hydrodynamics, has found a model which does not contain empirical coefficients, and at least, qualitatively correspond to the questions raised and many others.

S4. 7. Study of Features in Dynamic Processes in a Pressure Pipeline with Two Phase Mixture /151

Yu. M. Orlov (Perm')

In the operation of hydraulic control systems and systems of fuel supply for flight vehicle motores and space vehicles, emergency conditions may appear which are linked to unsealing of the suction piping, and pumping units. The pressure in the pipelines in this case sharply drops and intensive release of the gas and vapor phase from the working liquid takes place.

In order to eliminate an emergency situation on the craft, it is necessary for the pumps that feed the indicated systems to operate for a certain time under new conditions when there is increased concentration of the gas and vapor phase in the working liquid.

Publication [1] has presented the results of an experimental study of the behavior of a gas and liquid mixture in a pipeline with pulsation frequency 0 - 150 Hertz, average pressure p_H = 2.0 - 2.5 MPa with gas phase concentration α = 0.02 - 0.07.

However, the real operating conditions of the system significantly differ from the studied, both in the frequency of the process, and in the concentration of gas and vapor phase and for the average pressure p_H = 4.0 - 10.0 PMa. In order to clarify the features of the dynamic processes in the pressure pipeline with increased concentration of gas and vapor phase in the working liquid, a special study was made in which the pressure pulsations were measured at the outlet from the pump and at different points over the length of the pipeline. The pressure pulsation was

measured using piezo ceramic sensors.

The pressure pipeline was connected to the high - speed piston pump that developed pressure pulsation and flow with frequency f = 570 Hz. An expansion in the form of a container with loading throttle was connected in the final section to the pipeline. Increased concentration of the gase phase in the system was created by means of forced addition of nitrogen and helium to the suction pipeline.

Figure 1 shows the change in the pressure pulsation scope at the outlet from pump Δp depending on the average value of injection pressure p_H when gas is added and without it.

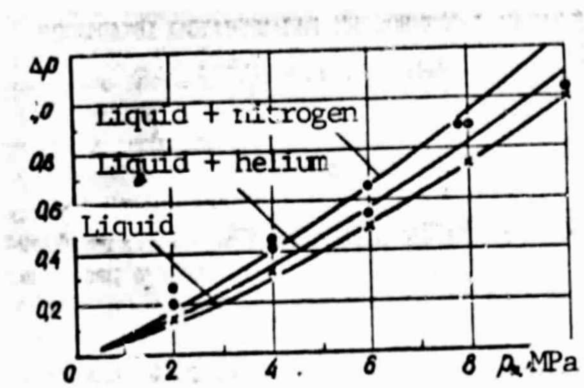

Figure 1. /152

Figure 2 shows the change in relative pressure pulsation scope over the length of the pipeline under the same conditions.

Analysis of the experimental data indicated that in all cases with an increase in gas phase concentration in the working liquid, an increase is observed inthe scope of pressure pulsation at the outlet from the pump, which depends both on the magnitude of concentration and on the properties of the gas phase. The nature of change in pressure pulsation over the length of the pressure pipeline with high static pressure indicates the presence of a standing wave with fixed arrangement of the maximum and minimums

of pulsation on the pipeline. Increase in gas phase concentration in the pipeline causes a rise in the maximum values of the standing wave amplitude, without changing the appearance of pressure pulsation over the pipeline as a whole. /153

Thus, with considerable increase in the gas phase in the working liquid, it is possible to have short - term operation of the pumping unit, taking into consideration the rise in the scope of the pressure pulsation and stresses in the pump and in the pressure pipeline line to it.

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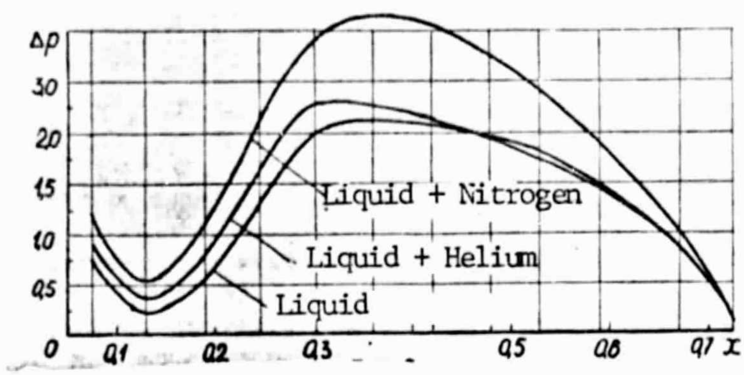

S4.8. Effect of Natural Convection on Nonstationary Combustion Mode

L. Yu. Artyukh, P. G. Itskova and A. T. Luk'yanov (Alma - Ata)

A theoretical comparison is made of the nonsingular and oscillating modes of nonstationary combustion in a moving liquid in weightlessness and when there is natural convection. Heat exchange with the environment occurs by the Newton law. It is assumed that liquid viscosity changes with temperature according to the exponential law. The dependence of the reaction rate of zero order on the temperature is determined by the Arrenius law. Motion is induced by pressure differential. Motion is considered steady -state.

The process is described by a system of heat and pulse transfer equations. At the first stage, a dynamic system of the second order with concentrated parameters is set in correspondence with this system. Possible modes are studied by the first method of Lyapunov. On the planes of parameters which define the process, equations were obtained for the boundaries of instability and nonuniqueness depending on the Prandtl number, Damkeller number, pressure differential, parameter characterizing the change in viscosity with temperature. The results of analyzing the concentrated system are confirmed by numerical solution to the problem in an unsimplified statement. The effect of gravitation on the nonstationary modes of viscous liquid combustion is revealed.

S4.9. Modeling the Process of Nonequilibrium Crystallization in Supercooled Monomelt /154

L. Yu. Artyukh, A. T. Luk'yanov, S. Ye. Nysanbayeva (Alma-Ata)

A study was made of the possible modes for crystallization of a melt in a two - phase zone with regard for the kinetics of crystal nucleation and their growth depending on temperature [1]:

$$r = K \exp\left(-\frac{U}{RT}\right) \exp\left(-\frac{E}{T(T_K - T)}\right), \quad (1)$$

where T_k--crystallization temperature, U--atom activation energy in the melt, R--universal gas constant, E--substance constant. As is apparent from (1), the rate of crystallization initially rises with a decrease in temperature, reaches the maximum, and with a further drop in temperature diminishes to zero. U for metals is small, and the melting temperature is comparatively high; therefore the first exponential multiplier exp(-U/RT) is close to one and the dependence of r on the supercooling is expressed by a curve which only has an ascending branch. When the equations of heat conductivity are studied with regard for the crystallization rate (1) (approximately and numerically) it was found that depending on the occurrence of the process, it is possible that crystallization

will be missing with large U even with considerable supercooling, or there will be partial or complete crystallization. An area with existence of nonunique stationary states is isolated in addition to these modes on the parameter plane.

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S4.10. Study of the Dependence of Carbon Dioxide Cryocondensate Growth Rate from Gas Phase on Pressure with a Change in Direction of the Gravitational Field

A. G. Karpushin and A. S. Drobyshev (Alma-Ata)

In an experimental study of the process of formation and structure of cryocondensates, the main difficulty is to create conditions that are the closest possible to the real that occur on large surface testing units or directly in outer space.

In our case, the process of measuring the growth rate of a cryocondensate from the gas phase consists of letting gas into the vacuum chamber with metal surface (backing) on it cooled to cryogen temperature. Part of the gas in this case is pumped out by vacuum pump, and part is condensed on the backing in the form of a solid phase which is also the object of study.

During the entire experiment, the temperature of the backing and the gas pressure in the chamber are maintained constant. The visual observations of the behavior of the forming cryocondensate were made through a viewing window. One of them in this case illuminated the chamber. A cathetometer measured the change in cryocondensate thickness.

The dependences obtained during the experiments of the cryocondensate thickness on the time were processed on the BESM-4 computer by the method of approximation to the polynomial of the

n-th degree. The polynomial coefficients were found and the derivative of the given function at zero was computed. It is also the unknown condensation rate at the initial moment in time. In this case it is also possible to ignore the effect of the temperature gradient over the cryocondensate thickness on the rate of its formation and to assume that the backing temperature (measured in the experiment) equals the temperature of the phase transition.

Visual observations indicated that depending on the thermodynamic parameters of the transition, the solid phase of carbon dioxide is either snow (formation temperature below 140 K) or transparent ice (formation temperature above 150 K). In the 140 - 150 K temperature range the cryocondensate was transparent thin scales. /156

Measurements were made of the growth rate of carbon dioxide cryocondensate with different ranges of the gas phase and backing temperatures. The findings indicated that the growth rate of the cryocondensate is not a monotonic function of pressure. On the first section, with an increase in the gas pressure in the chamber, there is a monotonic increase in the condensation rate. Further pressure increase results in a noticeable drop in the magnitude of velocity with its subsequent rise. The value of pressure at which the condensation rate drops depends on the temperature of the backing and rises with its increase. The obtained dependence of the growth rate of carbon dioxide cryocondensate on gas phase pressure can be qualitatively explained by the presence of two condensation mechanisms, gradual and normal, whose definitive role in the summary process of phase formation changes with a change in pressure.

The conducted experiments verified the effect of the gravitational field direction towards the backing plane on the growth process of cryocondensate. For this purpose the growth rates of the cryocondensate were measured with different orientations (from 0 to 180°) of the plane to the horizon. Within the limits

of experimental error (5 - 6%), no changes were noted in the cryocondensate growth rate from the backing orientation.

S4.11. Conditions for Development of Particle Grouping in Dispersed Systems

N. Ye. Tkachenko and S. Ye. Tkachenko (Kiev)

A dispersed mixture is examined: liquid - solid particles. A model is constructed for a two - component medium based on the statistical approach to describe particle motion and averaged forces of interaction between the phases from the known motion equations of one particle. The motion of liquid is described by equations of an ideal liquid, where the average forces of interaction between the phases are added to the right sides. In this case /157
the effect of small - scale liquid movements are taken into consideration.

A study was made of the change in motion of particles governed by external vibration effects on the liquid and particles at a certain moment in time $t = t_1$ in the end section of the pipe with weak and strong gravitational fields. Cases are examined where the opposite end of the pipe is 1) closed, 2) open. Vibration effects cause periodic changes in the particle and liquid movement rates in a certain section at a definite moment in time, which also governs the development of particle grouping. Conditions are indicated for the development of particle grouping in strong and weak gravitational fields.

S4.12. Heat Pipes for Weightlessness and Variable Orientation in a Gravitational Field

Yu. F. Maydanik, Yu. F. Gerasimov, Yu. Ye. Dolgirev (Sverdlovsk)

Heat pipes are among the most effective heat transmitting devices that are currently known. One can note that their development was stimulated by space research to a greater degree than any other. The first space test of a heat pipe installed on a satellite launched using the rocket Atlas Engine took place

in 1967. The pipe was made of stainless steel with water as the heat carrier. Studies and use of heat pipes in weightlessness were further rather extensive, in particular in the 1972 - 1973 NASA program. It has been suggested that they be used on space shuttles [1].

The heat pipes are highly effective under space conditions not only because they are reliable and have good weight and dimensional characteristics, autonomy and economy, but also because in weightlessness where there is no effect of gravitational forces on the return flow of heat carrier, their thermal productivity can be significantly increased.

However, the heat pipe which allows high heat productivity /158
both in weightlessness and under the influence of mass forces, in particular, inertia, regardless of the orientation in relation to their vector should be considered the most universal type.

The devices which satisfy these conditions are made in the form of a closed loop and contain capillary - porous material (core) with effective diameter of the pores 1 - 5 μm only in the evaporation zone. This makes it possible to provide fairly high capillary potential even when liquids are used with low values of the surface tension coefficient. At the same time, there is a significant decrease in the hydraulic resistance of the liquid and vapor transportation sections that are made separately from pipelines 3 - 6 mm in diameter. They can easily be given different configurations [2]. The length of these heat pipes that operate in any orientations of the gravitational field with 1q can reach 1.5 meters, and the magnitude of thermal load density (5 - 15) x 10^4 W/m^2 with steam temperature 50 - 100°C. Their thermal resistance in this case does not exceed 0.25 deg/W. The design materials used are stainless steel, nickel, titanium, and the heat carriers are water, acetone, freons and ammonia. The working characteristics of the acetone heat pipe of the examined type are presented in figure 1.

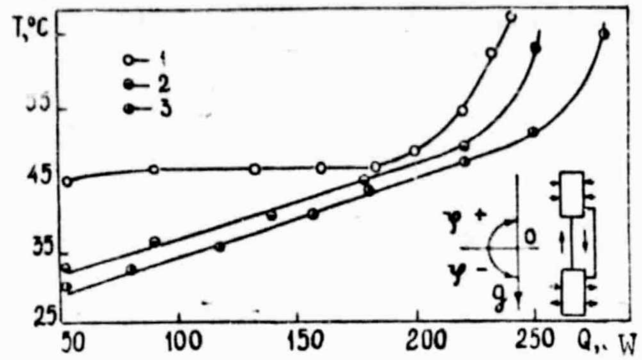

Figure 1. Dependence of Heat Pipe Wall Temperature in Evaporation Zone on Transmitted Heat Fluz

Key:

1. ϕ = +90°
2. ϕ = 0°
3. ϕ = -90°

In weightlessness which one can approximately model by horizontal arrangement of the device in the gravitational field, the heat transfer distance can be increased to 5 - 6 meters.

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S4.13. Possible Use of Electrohydrodynamic Heat Pipes for Cooling and Thermal Regulation of Objects in Weightlessness

M. K. Bologa, V. D. Shkilev (Kishinev)

Basic and applied research in the field of controllable heat pipes was started slightly over 10 years ago; nevertheless, basically new technical opportunities which guarantee effective and fine regulation of the temperature conditions of the objects allowed this class of heat exchangers to win general acceptance.

The need for controllable heat pipes in developing systems of cooling and heat regulation in weightlessness can be explained by the fact that maintenance of a constant temperature in the coolable object using the uncontrollable heat emission is only possible when unjustifiably large heat storage is used and with small change in the heat release in the object. In practice (cooling systems of different apparatus, furnaces for growing new materials), the powers that are needed for removal from the coolable object are often subject to large oscillations, and thermal stabilization is only possible when heat pipes are used with regulation of the parameters based on the feedback principle.

The heat pipes with passive (mechanical) feedback that use, for example, a tank with a bellows, have high inertia. One can isolate magnetic and especially electrohydrodynamic [1] among the /160
heat pipes with active (electrical) feedback. The latter class uses electrohydrodynamic phenomena to control the processes that are taking place. These heat pipes use dielectrics as the heat carriers, for example, freons. The temperature range of use of electrohydrodynamic heat pipes stretches from -200 to +400°C.

Evaporation and condensation, movement of steam and kinetics of evaporation because of the effect of electrical wind, removal of heat from the condensation zone, and movement of liquid over the core can be the controlling processes in electrohydrodynamic heat pipes.

The design of the electrohydrodynamic heat pipes capable of operating in weightlessness and equipped with active feedback is discussed.

An experimental study was made of the heat transmitting characteristics with small exceeding of the evaporator over the concentrator. This arrangement of the heat pipe in space simulates weightlessness conditions well.

The effect of the electrical field with intensity 25 kV/cm, promoting transportation of the liquid dielectric through the core increases the maximum thermal loads up to two - fold. The heat output coefficient in the evaporation zone in this case also increases up to two - fold. Change in field intensity in the evaporation zone made it possible in a broad temperature range to alter the heat transmitting characteristics of the heat pipes. A comparison is made with similar experimental data described in the literature [2].

Possibilities are discussed for using atomic high voltage batteries and high voltage solar transformers that recommended themselves well when operating in weightlessness as the high voltage sources of current in the heat pipes [3].

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S4.14. Use of Submersion Analogy to Model the Gravitational Force in Weightlessness

A. N. Vereshchagin (Perm')

The analogy suggested by S. G. Gutman and M. A. Bio [1,2] is that when a solid deformable body is submerged into a heavy liquid, the stresses in it with accuracy to stresses of comprehensive compression equal the stresses from the effect of volumetric forces $a = -(k - 1)\gamma g$ which are opposite to the actual gravitational forces. In the formula, γ--density of the body, $k\gamma$--density of the liquid, g--acceleration of the gravitational force.

Centrifuging of polymer models in an easily melting alloy or in mercury increases by almost an order the testing loads as compared to the normal loading on the centrifuge [3 - 6].

The effect of the gravitational force in weightlessness in addition to centrifuging can be attained by variable pressure applied to the body surface

$$p = p_0 + \lambda x,$$

where p_o--pressure on the body surface in the characteristic section, the x - axis is directed along the deformable body, and the beginning of the coordinates is in the characteristic section.

The pressure gradient must be opposite to the direction of the modeling gravitational forces. In this case, depending on the magnitude of p_o, rarefaction may be required on part of the body surface. The g - force coefficient is defined by the ratio $\lambda/\gamma g$.

A possible variantfor realizing the indicated method of modeling the gravitational force is gradual change in pressure along the tested body.

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2. Preliminary Results of Experiments on Crystallization of Solid CdTe - HgTe Solutions in Weightlessness /163

B. I. Golovin, V. S. Zinov'yev, A. V. Iz"yurov, N. V. Komarov, L. N. Kurbatov, Ye. N. Kholina, I. V. Barmin (Moscow)

Results of Experiments with CMT

Experiments on directed crystallization and liquid phase epitaxy of a semiconductor solid solution of cadmium - mercury - tellurium (CMT) which is of prominent importance for modern optical electronics were conducted for the first time in domestic and world practice on the program of scientific experiments on the Splav unit on 18 March 1976. An experiment on directed crystallization in a simplified variant was later realized in the joint Soviet - Polish program Intercosmos under the name Siren [1].

Directed Crystallization

Selection of the material and method for crystallization is determined by the fact that its production in the form of high quality monocrystals under normal conditions is linked to a number of technological difficulties governed to a great degree by gravitational forces. During directed crystallization under normal conditions, the components are separated by density on the melt - crystal interface, and gravitational convection intensifies this phenomenon even more [2, 3]. If special methods are undertaken to compensate for these phenomena during crystallization [4], then the obtained monocrystals have high density of the small - angular boundaries, a large quantity of inclusions of the second phases and high heterogeneity of the composition both in the axial and in the radial section of the bars [5, 6].

Extremeley low crystallization rate (fractions of mm per hour) [4] is required to suppress the concentration supercooling on the crystallization front to obtain CMT.

Special designs of ampoules with material and metal capsules withstanding pressure in irregular situations (with uncontrollable heating above the assigned) to 150 atm were developed for the experiments. For the first time in world practice, they sharply expanded the nomenclature of materials and processes studied in space. /164

As a result of the experiments conducted on the Salyut - 6 orbital station, monocrystals were produced whose quality differed drastically from their terrestrial analogs.

As it turned out, crystallization occurred without contact with the ampoule walls, which promoted a prevention of contamination and improvement in structure. The obtained monocrystals had a face in the final section.

The absence of separation of the components by density and suppression of convection of the gravitational type made it possible to produce bars with high macro- and microuniformity for composition, primarily in a radial section (figs. 1 and 2). The crystallization front in the middle part of the bar was essentially flat. However, it was severely twisted on the surface of the bar, which, as is indicated in publication [7], is governed by thermocapillary convection on the melt surface, the Marangoni effect.

The macro- and microstructure of the obtained bars differed strongly from the terrestrial analogs.

The experimental samples essentially lacked boundaries at small angles and cellular structure. Inclusions of second phases was not observed in the majority of bars (figs. 3 and 4).

The main reason for improving the structural characteristics of monocrystals was apparently the drastic decrease, and even,

Figure 1. Isoconcentrate Shape on CMT Sample Obtained in Weightlessness (x 5)

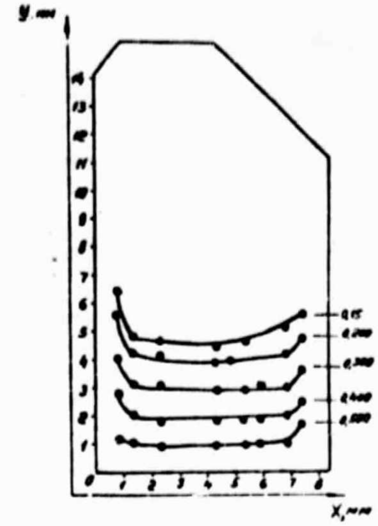

Figure 2. Distribution of Composition over Section of CMT Sample Produced in Weightlessness from MRSA Data

Figure 3. Microstructure of CMT Crystal Obtained in Weightlessness (initial part of bar) (x 130)

Figure 4. Microstructure of MRT Crystal Grown in Weightlessness (middle part of bar) (x 130)

Figure 5. Microstructure of Epitaxial CMT Layers Produced in Weightlessness (x 130)

Figure 6. Microstructure of Epitaxial CMT Layers Produced in Weightlessness (x 187)

possibly, complete elimination of the phenomenon of concentration supercooling before the crystallization front in conducting the process.

Liquid Phase Epitaxy

Experiments on liquid phase epitaxy of solid CMT solutions were conducted in isothermic zones of the "alloy" unit on a monocrystal backing made of cadmium telluride.

As a result of the experiments, monocrystal layers of solid solution of high structural perfection were formed with a flat boundary of the structure and good microuniformity. In contrast to the terrestrial analog, no spread of the structural defects was observed, in particular, dislocations in the cultivated layer. In the obtained layers there were no inclusions of the second phases and pore (fig. 5 and 6).

Thus, features of CMT crystallization in space made it possible to obtain results that are important both in scientific /165

and applied aspects.

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The number of the summaries in the collection corresponds to the number of the report in the program. The first number indicates the section, the second number indicates the report number within the section; the letter S designates the stand reports.

Here is an example of interpreting the designations in the author index:
Sidorov, I. I. 3.6, 190; S4.15, 220. This means that I. I. Sidorov makes the sectional report No. 6 in section 3, and stand report No. 15 in section 4; the summaries of the reports are published in the collection on pages 190 and 220 respectively.